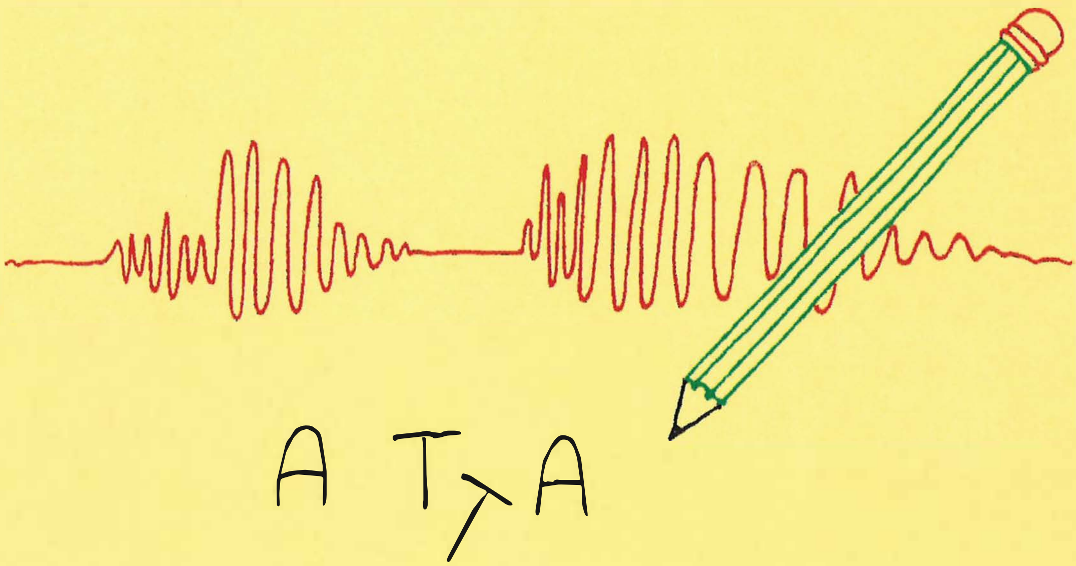
Ulla Richardson

Familial Dyslexia and Sound Duration in the Quantity Distinctions of Finnish Infants and Adults



STUDIA PHILOLOGICA JYVÄSKYLÄENSIA

EARLY LANGUAGE DEVELOPMENT AND DYSLEXIA -PROJECT

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UNIVERSITY OF JYVÄSKYLÄ

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ABSTRACT

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This study investigates the role of duration in the categorisation of speech sounds into prosodically distinct phonemes by dyslexic adults and their infants, in the Finnish context. The duration of sounds has a significant role in Finnish quantity distinctions and the quantity aspect is visibly marked in the Finnish orthography. Previous research has shown controversial evidence on the temporal processing abilities of dyslexics.

In the infant perception experiment a head-turn paradigm was used to test 6-month old infants' perception of speech stimuli in which the duration of a stop was varied. There were 89 subjects, half of whom were infants with high genetic risk for dyslexia (GR+) while the other half were controls (GR-). The results indicated that the GR+ infants require significantly longer duration than the GR- infants to shift their perception from the short to the long quantity category. The same experiment adapted for adults showed that also adult dyslexics may have a deficiency in processing temporal information.

The same adults and infant subjects took part in production experiments. The results showed that the GR+ infants differed from the adults more than GR- infants in using durational cues for (C)VCV and (C)VCCV structures. In particular, the secondary cue in these word structures appeared to be troublesome for the GR+ infants. Also the dyslexic adults differed from the control adults in the use of the secondary cue in CVCV structures. The findings suggest that there may be a basic temporal processing deficiency in dyslexics which is apparent early in their development.

Keywords: dyslexia, duration, quantity, language development, Finnish, speech percpetion, speech production, categorisation

FOREWORD

This work began from my interest in the durational aspects of speech sounds. In particular I was curious to find out how the two sides of communication affect each other in language learners. So when Professor Matti Leiwo asked me in 1992 to join the newly founded dyslexia project "Jyväskylä Longitudinal Study of Dyslexia (JLSD)," at the University of Jyväskylä, I was ready to take the plunge and commit myself to further research in my own specific area of interest. I myself have struggled in various ways with written language; especially with spelling words. Because of this personal experience, I was more than eager to get involved with a project dealing with dyslexia. In fact, as evidence of my difficulties with written language, I would not be surprised if a number of those myriad spelling mistakes have remained in the final version of this study.

In the early days of the multidisciplinary JLSD project, the linguistic contingent was not very large, but led by Professor Leiwo we quickly branched out and created our own project, "Early Language Development and Dyslexia," which is specifically linguistic by nature. The work reported here should be regarded mainly as the product of the linguistic project, although it would not have been possible without the larger JLSD project. All the knowledge, facilities, connections, etc. provided over the years by the project led by Professor Heikki Lyytinen (leader of the JLSD project) has been invaluable.

As I have mentioned, Professor Leiwo introduced me into this project. I am thankful for this opportunity and would like to express my deepest gratitude for all the support that he has given me during my research. I particularly value the fact that he has trusted me all along with my ideas and allowed me to work independently to the extent that I have wanted. I am also thankful for his insights into many aspects of linguistics, psycholinguistics, language development and various aspect of life in general, which he has generously shared with me. I believe that this work would not have been possible without Professor Leiwo's encouragement and support, for which I thank him. Also he gave me the opportunity to go to Los Angeles during 1996 to conduct further research on the subject.

I am grateful to Professor Florien Koopmans-van Beinum and Professor Sven Strömqvist for their valuable comments and suggestions about language development in the earlier stages of this research but most of all I appreciate the specific comments they gave on this dissertation in their facility as evaluators. Both were extremely co-operative in working as fast as they did and thus keeping to the virtually impossible time schedule asked of them but also in reading my work with great attentiveness.

I would also like to thank Professor Jaakko Lehtonen for his comments during the early stages of my research. In addition, his own dissertation on Finnish quantity has been an immensely important source of information to me. I would also like to thank Associate Professor Pertti Hurme for his comments on the preparation of the stimuli for the perception experiments and

for guiding me into the fascinating world of phonetics at the beginning of my university studies.

The fact that I have conducted this study within two projects has had a great impact on this work. And once again it cannot go unacknowledged that without all the support and work various members of these projects have done for me during the years this dissertation would not have been possible. I will try to thank each and every one of them but I am sure that all the people who deserve to be mentioned will not be mentioned here and I apologize for that.

I shall begin by thanking all of the members of the two projects. Individually I would like to mention some people whose contribution to this study has been particularly significant. I would like to thank Sirpa Jokinen for everything she has given and done for me over the years. We have worked together on the linguistic side of the projects virtually from the beginning. She has been a very good friend and collected a large part of the infant perception data together with me. She also took part in the important stages of the research when I was developing and discussing with people the stimuli that would be used in the perception experiments. She had an even bigger and more crucial role in designing the imitation test for the infants. Without her contribution that experiment would not have been conducted in the form that it was as reported here. Another important person in terms of data collection for this study was Kirsti Eklund. She was virtually solely responsible for collecting the imitation data. For her endurance and friendship I am truly grateful.

I also gratefully acknowledge the assistance in data collection of Kenneth Eklund, Kirsi Heiskanen-Nikula, Minna Hentilä, Karita Koivisto, Marja-Leena Laakso, Pirkko Leppänen, Anna-Maija Poikkeus, Minna Rasilainen and Kirsi Sundholm. Various types of technical support were provided by Erkki Ahvenainen, Heikki Melkinen, Timo Rossi, Seppo Pesonen, Pertti Snellman, Henry Teheranizadeh (at UCLA) and Lauri Viljanto, which is also greatly appreciated. In particular, Timo Rossi played a crucial role in the preparation of the computer program for the main perception experiments. Without the endurance and knowledge of statisticians Jussi Kemppainen and Asko Tolvanen this work would not be done yet.

From outside the project, I would like to thank Professor Patricia Keating for her insights into phonetics and phonology and dyslexia which she generously shared with me while I was in Los Angeles. I am also most grateful to her for allowing me to use the analytical equipment at UCLA's phonetics department as well as for allocating me a place where I could work there. In addition, I am grateful for the discussions I had with Matt Gordon and Richard Wright at UCLA's phonetics department and for the concrete guidance they gave while I was analysing my data. The insightful work of Professor Patricia Kuhl has had a profound impact on the orientation of this study. The information she together with Karen Williams provided me about the head-turn paradigm used in this study has been invaluable. Also discussions and co-operation with Professor Olle Engstrand, Associate Professor Francisco Laserda and Professor Carol Stoel-Gammon are well appreciated.

My thanks to Inkeri Pasanen for allowing me to use her photograph. The financial support provided by the Academy of Finland, the Ellen and Artturi Nyyssönen foundation, and the University of Jyväskylä, is also appreciated.

My appreciation also to the Studia Philologica Jyväskyläensia series for accepting this dissertation for publication.

This study could not of course been completed without the participation of the children and parents in the dyslexia projects; my deepest gratitude to them. Last but by no means the least, I would like to thank my family without whose consideration and endless support my task would have been much harder than it was.

Jyväskylä, 27th January 1998

Ulla Richardson

CONTENTS

1 INTRODUCTION

1.1 Study on duration in Finnish quantity distinction

The purpose of this study is to investigate the role of duration in the categorisation of speech sounds into prosodically distinct phonemes by dyslexic adults and by infants with high genetic risk for dyslexia, in the Finnish context. The Finnish language is perhaps best known for the characteristic features of its prosody; specifically, for its extensive quantity system. Unlike some of the Indo-European languages, e.g., Swedish, the Finnish quantity system is not restricted by stress. In fact, the Finnish quantity system seems to be affected by no prosodical feature other than duration (Lehiste 1970, Lehtonen 1970). The significant role of duration in Finnish quantity distinctions is relatively uncommon among other so called quantity languages in which, e.g., quality, the duration of adjacent sounds, fundamental frequency or the intensity of the sound co-varies with the length of the phoneme. The only few restrictions that are made on Finnish quantity are mainly phonotactic in nature. All vowels and consonants with only a few exceptions (j,v,h)[1] can be either long or short, but only long consonants are restricted in that they cannot occur at the beginning or the end of a word.

The quantity aspect is not merely a feature of spoken Finnish. Quantity, unlike other prosodical features of speech, is also visibly marked in the Finnish orthography, where the sound segment which is perceived as short is written with one letter, and that which is perceived as long is written with two identical letters. This fact deserves emphasis since a part of reading proficiency is the ability to superimpose onto a written text the proportions of the oral

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1 There is also a restriction on the occurrence of the voiced alveolar stop /d/, in that its geminate form can only appear in the intervocal position of loan-words. This phoneme otherwise occupies a relatively special position among the Finnish phonemes since it cannot occur at the beginning and at the end words of Finnish origin (Karlsson 1982, 57) and since it does not belong to all the dialects of Finnish.

signals that usually do not have a graphical representation in the written format (Fries 1963, 130).

In this study the investigation of the durational dimensions is focused around (C)VCV and (C)VCCV structures. Although, in general, the principles of the use of duration in these word structures are relatively straightforward, the way in which the durational dimensions are demonstrated in various dialects varies to some extent. This variability is mostly due to the durational differences of the word final distinction in the CVCV structure when compared to that of the CVCCV structure. As a rule, the word final vowel is relatively long in the CVCV word. However, the prolonged duration of the word final vowel can in some dialects appear twice as long as in other dialects. Wiik (1985, 273-277), in his extensive study on the durations of vowels in Finnish dialects, measured that in some speakers the word final vowel could be twice as long as in other cases (e.g., in general this was the case between the speakers of South-West Finland, where the average duration was over 118 msec, and speakers of South-Ostrobothnia, where the average duration was under 88 msec). In the more reliable proportional measures in which the speech tempo does not have a decisive role, the variability of the duration of the word final vowel in the CVCV structure in comparison to that of the CVCCV structure can also be as large as from just over 100% to 300%. Therefore, although in principle the vowel is short in this position it can also be characterised as a half-long vowel. In general, the duration of the half-long vowel is relatively long in the region of Central Finland from where the subjects of the main experiments of the present study originate. Although geographically the area is not large, several different dialects are spoken in this area. The dialects of Central Finland could be classified as belonging to the transitional dialects of Savo as well as those of Päijät-Häme and Central Häme (Itkonen 1965, 30-31), and in all of these dialects the word final vowel of the CVCV structure can be characterised as a half-long vowel. Furthermore, by restricting the area in which the subjects live, it is considered that the dialectical variations of the feature in question does not play a decisive role in the outcome of the results. Details of quantity distinction are returned to later on, in Chapter 2.

1.2 Study on language development and the language of caregivers

The use of duration in categorising speech sounds is studied in young infants and in adults. The infant subjects of this study are as young as 6 months old in the perception test, and the production data is collected from the same infants when they are 18 months old. The data is experimental by nature since all the data are collected from experiments. The perception data were collected from a behavioral experiment using a specially adapted form of the head-turn paradigm originally developed by Moore, Wilson and Thompson (1977), which was further developed by Kuhl (see her 1985b article for details), and which has been used successfully ever since in infant studies. Altogether, data were collected from 176 six-month old infants. The production data were collected in an elicited imitation task, using both the speech model of the parents and that of a videotaped woman which was used to coax the infants to repeat the experimental stimuli. The production data were collected from the same infants participating in the perception test when they had reached the age of 18 months. The data of 89 infants in the perception test is included in the results and that of 64 in the production test.

The ability of young infants to categorise perceptually distinct speech sounds has been demonstrated in the past (see e.g., Eimas 1996 for review). The use of duration in the categorisation of speech sounds in infants has mainly been demonstrated with regards to the VOT values of consonants: infants as young as one month old have been shown to categorise sounds perceptually (Eimas, Sigueland, Jusczyk & Vigorito 1971), and there is evidence on categorising labelling abilities in the speech of toddlers (de Boysson-Bardies, Bacri, Sagart & Poizat 1980, Kuijpers 1993). There are, however, no studies on young infants' ability to group sounds in quantity degrees according to their duration. As is the case with virtually any features of language development in the Finnish context, there only exist a limited number of observations on the development of the quantity aspect in infants acquiring Finnish (Iivonen 1994). This aspect, however, has been studied in somewhat older children (3 and 6 year olds) in two studies with a subject group size of ten, which is an unusually large population in studies of language development in the Finnish context (Hurme & Sonninen 1982, 1985). Thus, the present study is the first attempt to systematically investigate with a sizable number of subjects the role and nature of the development of the quantity system in infants.

The length of a phoneme (short or long) has an important distinctive function in the Finnish language, which makes the development of temporal processing particularly interesting in this context. The nature of quantity in the Finnish language moreover enables a systematic investigation of this phenomenon, because the occurrence of length in a segment is not conditioned by surrounding segments. Since quantity seems to be an integral feature in the Finnish language, both in written and spoken language, it could be assumed that this feature, or at least some aspects of it, would gain the attention of infants. Since the infants are studied here already when they are at the preverbal stage of language development it is possible to tract down indications of early markers of the quantity distinction processing.

There exists evidence on the importance of spectral aspects to infants in so far as it has been shown that ambient language can effect the perception of vowels as early as 6 months of age (Kuhl, Williams, Lacerda, Stevens & Lindblom 1992) and consonants somewhere between 10-12 months (Werker & Tees 1984). Yet, several studies indicate that prosodical features such as intonation and stress of the ambient language are among the first to be acquired in the early stages of language development (Mehler, Bertoncini, Barriere & Jassik-Gerschenfeld 1978, DeCasper & Spence 1986, Jusczyk, Hirsh-Pasek, Kemler Nelson, Kennedy, Woodward & Piwoz 1992, Jusczyk, Cutler & Redanz 1993). It has been suggested that prosodical features of speech facilitate the production of words in early language development (Kent, Mitchell & Sancier 1991). In addition, there is also some evidence that acoustical features of prosody may be among the more stable aspects of early motoric skills related to speech (Kent et al. 1991, MacNeilage & Davis 1991). These findings have led to the suggestion that infants become sensitive to those aspects of the native phonology that are cued by more global prosodic features at an earlier age than they do for strictly phonetic aspects of the native phonology (Jysczyk et al. 1992, Cutler & Mehler 1993).

The focus on the prosody of ambient language becomes apparent since, when addressing young infants to gain their attention, caregivers tend to speak in a manner in which both the physical dimensions and the affective content clearly reflect the distinguishing factors of prosodical features in the specific language (Fernald & Simon 1984, Fernald, Taeschner, Dunn, Papousek, Boysson-Bardies & Fukui 1989, Peters & Strömqvist 1996). It seems plausible that such a strong prosodical feature involving duration as the quantity system in Finnish would be pronounced in the language of the caregivers and thus gain attention from infants. Although the main focus in this study is on the infants, the language of their parents is also studied. Thus, it is of interest here to look into the developmental side of the processing of the quantity distinction but also to see how this same feature is processed in the parents and how they manifest it when attempting to make the infants produce the distinction in their speech.

1.3 Experimental study on speech perception and speech production

As has already been mentioned, durational dimensions in this study are examined in both speech perception and speech production experiments. One of the views among linguists is that speech production and speech perception may reflect on each other (e.g., Liberman & Mattingly 1985, Ingram 1989). This suggestion that the two sides of communication are related is, thus, taken into the consideration in design of this study.

The data on perception and production are connected in three ways. Firstly, the infant and adult subjects taking part in the main experiments of the study are the same in both production and perception experiments. Secondly, the infants and the adults belong to the same families, i.e., the adults are the parents of the infants. Third, the same pseudoword stimuli (*ata-atta*) are used in the perception tests and the speech imitation test of the infants.

In earlier experimental studies on quantity and duration, stop consonants are favored as speech stimuli. Here also the research parameter duration is studied in experiments in which the voiceless alveolar[1] stop has a central role. From the point of view of language development, the use of voiceless alveolar stop in the experiments is justified by evidence that this stop is one of the first consonant sounds used by children, and it occurs quite frequently in the speech of infants under the age of two (e.g., Menyuk 1968, Iivonen 1993). There are

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1 To be precise, the consonant in question is produced more in the dental area than in the alveoli in Finnish (Suomi 1980).

many further reasons for the favoring of stop sounds in psychoacoustical studies such as the perception experiments employed here. Firstly, the stops are acoustically relatively easy to distinguish from the speech wave: they are often characterised by silence (an oral occlusion is heard as silence in the voiceless stops), voice bar, burst, aspiration, VOT and rapid formant transitions. Secondly, during the closure of a stop there is a noticeable acoustic gap in the formant pattern which can be manipulated without losing the naturalness of the speech sound. More importantly, previous studies have demonstrated that the duration of the silent gap has a decisive function in the categorisation of sounds into the two Finnish quantities (Lehtonen 1970). Finally, the stops are interesting because they are very effective, unlike vowels and some other consonants, in demonstrating the non-linearity of perception (due to their shorter duration and lower intensity, which makes them less accessible to auditory analysis). Non-linear perception of speech is seen in the phenomenon of categorical perception, which is under study here because there is evidence that the Finnish quantities are perceived categorically (e.g., Lehtonen 1970 and 1974).

In its entirety the present study comprises six experiments, two of which are conducted on infants and four on adults. As was already mentioned, the experiments are related to each other in a number of ways. The first two experiments deal with perception of speech stimuli employing adults as subjects. The pseudoword *ata* is used as the basis in the stimuli continuum of Experiment 1, and the stimuli continuum used in Experiment 2 is constructed from the pseudoword *atta*. The categorisation functions revealed by means of identification tasks[1] are studied using changing duration of an occlusion in the word medial stop consonant as the research parameter. The information gained from these identification experiments forms the basis for the design of the main two perception experiments. In the main perception experiments the discrimination and categorisation[2] abilities of the subjects are investigated. The stimuli continuum used in both of the experiments is the same as in Experiment 1. There would be no grounds to interpret the results of mere auditory discrimination and categorisation tasks without knowledge of the way in which the exactly the same stimuli were identified. Therefore, the information gained from the identification tasks is used here to facilitate the interpretation of the results of Experiment 3 and 4. In Experiment 3 the auditory categorisation abilities of dyslexic and control adults are investigated. In Experiment 4 the discrimination and categorisation abilities of young infants whose parents participate in Experiment 3 are studied. The results of the experiment employing adults as subjects are used as a point of reference for the experiment using infant subjects. The last two experiments are production experiments in which the subjects are the same who participated in perception

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1 An identification task refers here to a perception task in which listeners are required to identify by means of writing down what they had heard.

2 A discrimination task implies merely that subjects indicate when they perceive a difference between stimuli. A categorisation task inherently means that subjects need to perceive a difference between stimuli, i.e., discriminate, but in addition they need to partition stimuli into categories which are comprised of features that would be identified identically.

experiments 3 and 4. In Experiment 5 the production of the quantity distinction of adults subjects is examined, and in Experiment 6 that of infant subjects is under investigation. The minimal pair *ata-atta* is once again used as stimuli in the experiments with infant subjects. The reason for utilising pseudowords as stimuli in this study is based on a number of studies on dyslexia showing that dyslexics have special processing difficulties with pseudowords (e.g., Stone & Brady 1985, Catts 1986 & 1989, Gathercole & Baddeley 1993, Hansen & Bowey 1994, Apthorpe 1995). Another reoccurring theme in the analysis of the production data is the fact that the durational dimensions are focused upon. The same research parameter is used in the analysis of the minimal word pair *mato-matto* which is used in experiments involving both adults and infants. In this way the data on infants are compared to those on adults. Furthermore, by studying both the production of words and pseudowords the established representational aspect of the quantity system can be studied in comparison to the processing of the unfamiliar pseudowords. Finally, the main perception tests are connected to the productions tests by virtue of the fact that the subjects belong to two research projects on dyslexia.

1.4 Linguistic study on dyslexia as a part of two research projects

This study belongs to the field of linguistics. More specifically, the approach of the study could be categorised as belonging to the fields of experimental phonetics and psycholinguistics. The fact that this is above all a linguistic inquiry should be reflected all through the text and should be kept in mind since there is no attempt here to cover many different aspects of the data which undoubtedly would be beneficial to dyslexia research in the long run.

The nature of the problems tackled here warrants a linguistic point of view simply because the data is linguistic and the symptoms concerning reading impairment, which form one side of the study, emerge from orthographically represented linguistic material, i.e., reading and writing. An attitude has prevailed, however, according to which reading and writing are considered to be somehow outside of the linguistic realm, since these two processes involve optical shapes rather than acoustic speech signals. But orthography should not be considered to be somehow special and outside language processing. Indeed, Liberman (1985, 97) very appropriately points out the nature of reading and writing when she says that the optical forms of the orthography does not provide meaning more directly to readers than the auditory patterns of the acoustical signal do to listeners. It should be remembered that just as speech is made up of strings of abstract, meaningless phonological units, so visual representations of words are arbitrary and provide no meaning directly (Klima 1972, Liberman 1985).

This linguistic study is one product of two ongoing Finnish projects. First of all, this work forms a part of a solely linguistic project "Early Language Development and Dyslexia" headed by Prof. Matti Leiwo from the Finnish Department at the University of Jyväskylä. Secondly, this work belongs to a large interdisciplinary project "Jyväskylä Longitudinal Study on Dyslexia" headed by Prof. Heikki Lyytinen from the Department of Psychology also at the University of Jyväskylä. These projects are extensive already by virtue of the fact that the number of subjects who are included is large (176 families), and because the subjects are required to participate in the projects for many years.

These two longitudinal projects were formed in order to study comprehensively the prevailing communication disorder dyslexia. A common aim of the projects is to find early possible precursors for dyslexia. This is a far from being an easy task considering the fact that knowledge on dyslexia is still relatively limited. The lack of knowledge, in spite of the fact that this disability has been acknowledged since the publications of various pioneering investigations during the nineteenth century (for more information see Seymour 1986[1]), is reflected in the commonly cited definition of dyslexia in which Critchley (1970, 11) summarises the definition proposal by the members of a congress of neurologists as follows:

> *Specific developmental dyslexia.* A disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence, and socio-cultural opportunity.

The above definition shows that dyslexia is still largely defined by the exclusion of facts. This is also the case in this study, in which the term *dyslexia* will be used to refer to persons who find it continually and severely difficult to read and write correctly regardless of adequate opportunities to learn, and these difficulties cannot be traced to any known cause, such as deficiency in eyesight or hearing, or mental retardation, and neither is there an obvious damage in the brain. In other words, dyslexia is considered here as a form of communication impairment which surfaces with severe and often selective problems in acquiring particular skills for reading and spelling. The fact that writing and/or spelling is not explicitly stated in Critchleys's definition is the only point of disagreement between his definition and the one used in this study. Although reading skill may implicitly include the skill to spell words correctly (since, for example, if one is able to read one would notice a mistake in spelling if the text is monitored while writing), spelling is considered here as a separate process from reading involving among other things monitoring, and, therefore, it is mentioned explicitly.

Generally, the term dyslexia is used to distinguish between persons with solely reading and spelling problems and persons with other type of communication impairments such as aphasia and dysphasia, as well as from those with severe articulation impairments. In addition, there are studies which

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1 For more information on the history of the investigations on dyslexia see e.g., Benton, A.L. 1975. Developmental dyslexia: neurological aspects, Advanced Neurology, 7:1; Critchley, M. 1975. Developmental dyslexia: Its history, nature and prospects. In D.D.Duane and M.B. Rawson (Eds.) Reading, Perception and Language. Baltimore: York; Thomas, C.J. 1905. Congenital "word-blindness" and its treatment, Opthlamoscope 3: 380.

indicate that dyslexic children can be differentiated from children with other learning disabilities (Rudel, Denckla & Broman 1978, Denckla, Rudel & Broman 1981, Rudel, Denckla & Broman 1981). However, there are some researchers who are of in the opinion that in practice it is virtually impossible to distinguish a special group of persons who have problems solely with written language, and, thus, the very existence of a specific reading and spelling disorder has been repeatedly questioned. In this study this controversy about the existence of pure dyslexics is acknowledged in the selection of the subjects for the dyslexia group. The dyslexic subjects were selected in such a way that all the available information was utilised in order to ensure that they have difficulties purely with written text and that they have as homogenous backgrounds (history of difficulties with written language, family history of dyslexics, adequate IQ-level, social background, education). In addition, their present written communication skills were diagnosed with specific tests invented for the purposes of these two research projects. We will return to the selection of the subjects later, in Chapter 3, since in this kind of study the selection of subjects has a crucial role and a thorough description of the selection criteria is needed for the interpretations and possible generalisation of the results.

It should also be pointed out from the above cited definition by Critchley that the term *developmental dyslexia* is used to make the point that there exists more than one type of dyslexia. The term developmental dyslexia[1] is used to refer to persons who are considered to have dyslexia from the birth. There are also persons who have previously been able to communicate through written language but have acquired dyslexia later on in life, for example, as a result of an injury to brain. This type of dyslexia is referred to by the term *acquired dyslexia*. In this study purely developmental dyslexia is under investigation. There have also been several attempts to divide dyslexics into subtypes according to the types of mistakes they make. In this introduction, however, only a general framework is provided on the subject matter at hand, but there will be an attempt to fill in some of the relevant intriguing details on the bigger picture of dyslexia later on in the Chapters 3 and 4. At this point it will suffice to note that clinical observations regarding underachievement in written language are by no means uniform, and the need to improve therapeutic strategies has played a part in making researchers focus increasingly on the different manifestations of the problem.

Dyslexia is a relative disorder varying mostly in the nature and amount of mistakes dyslexics make. In fact, most people at least to some degree are familiar with dyslexic problems since the typical mistakes that dyslexics make are also made by learners to some extent. Typical dyslexic mistakes in reading and spelling have been internationally reported to include at least the following (see Seymour 1986, 4): substitution of letters which are similar in form (b and d, m and n); substitution of letters due to sounds which are similar (b and d, t and d, k and g); substitution of whole words which are semantically similar (chair for sofa, cat for dog, winter for summer); inversion of letters in a

1 The term developmental dyslexia can be credited to Critchley himself since he was among the first to focus on the division between developmental and acquired dyslexia.

syllable or of syllables in a word (er for re , pre for par,); inversion of letters in syllable boundaries (nr for rn; whole syllables can be reversed (ovara for orava[1]); transposition or omission of letters or syllables (percption for perception); difficulty in interpreting complex sounds (witch for which); difficulty in grasping the outline of a text, and difficulty in grasping the whole shape of a letter (top or bottom or one side of a letter could be missing). Obviously these are only a selection of the possible error types dyslexics exhibit, but the purpose of listing these errors is an area of considerable width in written language with which dyslexics may have problems. Furthermore, it should be noted that the selection of the types of mistakes made varies in different dyslexics.

The frequency of dyslexia is estimated to range between 3 to 15 percent of the population[2]. Several studies (see e.g., Debray-Ritzen 1987) on dyslexia also note that there seems to be a significant disproportion of dyslexics between sexes. For example, in accordance with many other studies, Debray-Ritzen (1987, 22) states that in his projects they found a proportion of male to female dyslexics of 3 to 1.2 in a survey of 200 children. In this study the estimation that 3 percent of population suffer from severe cases of dyslexia is utilised in the design of the projects by focusing the research effort on these severe cases. Severe dyslexics make grave persistent mistakes when they attempt to deal with written texts. For example, in addition to the above mentioned mistakes, they cannot distinguish where one letter ends and another begins, they can only distinguish a fraction of the letters from a word (one dyslexic could only distinguish the letters <cfn> from the word *California*) or they spell words backwards or upside down.

The extent of suffering becomes evident to anyone who has encountered severe dyslexics. Many different areas of life seemed to be affected. One of the most obvious consequences of the condition is that it can seriously impair school achievement and generally interfere with the acquisition of information from written sources. Generally, dyslexics have been observed to have various psychological problems, such as problems with emotional-adjustments and self-esteem (Bell, Lewis & Anderson 1972, Huntington & Bender 1993), depression (Livingston 1990), anxiety (Cornwell & Bawden 1992), dysfunctional attributes (Bryan & Bryan 1990), poor achievement motivation (Oka & Paris 1987), and inattentiveness and overactivity (Hinsahaw 1992). There is no easy answer as to whether these characteristics are related to or act as a prerequisite for the condition. Several studies have in effect reported no negative consequences of dyslexia for example on personality traits (Abbott & Frank 1975). It is, however, important to acknowledge also the possible emotional suffering of the dyslexic individuals in order to understand the

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1 *Orava* is the Finnish word for a squirrel.

2 For example Debray-Ritzen (1987, 22) estimates the frequency to be approximately 8% and Geschwind (1985, ix) reports that dyslexia affects 3 to 6 percent of school-age children. Although the frequency estimations can be useful for the purposes of subject screening they should be treated with some caution since several factors can have a strong influence on the estimation figures like factors such as the definition of dyslexia and the language and cultural context in which estimations are made.

seriousness of the condition. The need for more knowledge on the impairment is urgent.

The causes of developmental dyslexia are yet unknown. Several suggestions have been made during the last 30 years of focused investigation using different scientific approaches such as developmental psychology, cognitive psychology, neurology, special education and linguistics. Some theories suggest that the disorder seems to be dependent on fundamental cognitive disabilities (e.g., Seymour 1986) and that the specific difficulties with written language result from a left cortical hemisphere dysfunction (Wilsher 1987, 95). Also on the basis of experimental work on linguistic skills at the phonemic level, some researchers have suggested poor linguistic abilities in for example rhyming and phonemic analysis to be a cause for dyslexia (see Wagner & Torgesen 1987, Bryant, MacLean, Bradley & Crossland 1990). These suggestions are only a sample of a large number of theories on the causes of dyslexia. Because of the lack of experimental evidence (in particular when theories on general cognitive disabilities have been proposed) or the fact that the evidence is reliable only for a part of the dyslexic population (when poor linguistic abilities have been pointed out) none of the suggestions put forward so far is adequate in explaining the cause/s behind the large variety of dyslexia.

There is, however, one factor behind dyslexia which is generally agreed upon. Numerous studies have shown that a genetic factor may well explain the findings regarding a highly significant amount of family aggregation in dyslexia. The idea of the genetic factor was first put forward already in 1907 and was confirmed further by the work of Hallgren (1950) who found a familial history of dyslexia in 89.7% of cases in a population of 160 dyslexics. Since then study by study has provided even more evidence on the genetic factor. For example, Debray-Ritzen et al. (1987, 27) found that in all of their populations over the years there was clear evidence on the familial history in dyslexia: in a study conducted in 1966 out of 110 children they found a familial history of the disorder in 53.6% of cases (in the control study the figure was 7%), in 1971 out of 108 children 52% had a familial history, and in 1979, 62% of 200 children had a familial history of dyslexia. More recently Lubs, Rabin, Feldman, Jallad, Kushch & Gross-Glenn (1993) showed that 67 children out of 74 subjects with a dyslexic parent showed signs of dyslexia. Similarly, studies on twins have provided evidence on the genetic factor behind dyslexia (Gilger, Pennington & DeFries 1991a). But as Echenne and Cheminal (1987) note, although the genetic factor seems to be undeniable, it is still virtually unknown what the seemingly genetically transmitted factor/s behind dyslexia is/are.

In this study the fact that genetic factor may be behind a large number of cases of dyslexia has had an important impact on subject sampling. In order to find early precursors for dyslexia infants are followed up from birth onwards at least until they reach the age of 10 (Lyytinen 1997). And because we are dealing with a problem that becomes fully apparent and is diagnosable only when children try to learn to read and write (usually no later than 8 or 9), the selection of infants has to be founded in order to concentrate the research effort on subjects who are likely to be dyslexics. Therefore, the family history of dyslexia has been carefully mapped in the selection of subjects for the purposes of the two research projects. Also the fact that the data in this study are collected from 6 and 18 month old infants means that the results can only be considered as preliminary at this point with regard to the dyslexia aspect. In the future, when the subjects have reached the age 10 and it can be established who is dyslexic and who is not, the results of this study will have to be re-analysed.

Finally to round up this relatively long excursion into the domain of dyslexia the purpose of which has been to form a framework for the study, we turn to the connection between dyslexia and duration, which is the main research parameter here. In the Finnish language, quantity, with duration as its main determinative feature, has an important phonological function; there are two distinctive quantities and the use of the long instead of short quantity can change the meaning of a word (e.g., *tuli* means 'fire' and *tuuli* means 'wind'). As was mentioned earlier, the quantity of speech sounds is visibly marked in Finnish spelling. The relevance of studying the quantity aspect, or more specifically duration, in connection with dyslexia was first pointed out in a study which showed that nonfluent readers and writers of Finnish seem to make a disproportionate number of quantity errors in relation to other types of error, when compared to fluent readers (Lyytinen, Leinonen, Nikula, Aro & Leiwo 1995).

There is also some evidence on dyslexics' perceptual deficiencies in perceiving stimuli with varying durations. Steffens, Eilers, Gross-Glenn and Jallad (1992) results demonstrate that it is necessary for adult dyslexic individuals to perceive longer silence duration than fluent readers in order to transfer their perception from one speech category to another (/sa/ to /sta/). A study by Watson (1992) showed that dyslexics performed significantly worse on duration discrimination task (using tones as stimuli) than nondyslexics. McCroskey and Kidder (1980) found in an auditory fusion task that dyslexic children aged 7 to 9 required significantly longer interstimulus intervals than nondyslexics to perceive two pure tone pulses as separate. Also Tallal (1980) has suggested that people with language disorders including some dyslexics have an auditory temporal deficit in perceiving speech sounds as well as nonspeech sounds. She bases her suggestion on the results of a temporal order judgment task in which dyslexics performed significantly worse compared to nondyslexics when the rate of stimulus presentation was fast. This suggestion of Tallal's on the deficiencies in temporal processing of dyslexics has been criticised over the years (see e.g., Studdert-Kennedy & Mody 1995 for the most recent criticism). Mody, Studdert-Kennedy, and Brady's (1997) replication study of Tallal's studies also showed indications that the claim regarding temporal deficiencies in dyslexics is not necessarily founded. The present study is an attempt to throw further light on this controversy regarding the possible temporal processing deficit in dyslexics by providing experimental information on the truly temporal aspect in terms of duration in the speech processing of dyslexics as well as those at risk of becoming dyslexics.

Apart from the findings showing deficiencies in the speech perception processes of dyslectic individuals there is also some evidence of output phonological impairments in developmental dyslexia. For example, Catts (1986) showed that dyslectic adolescents made significantly more speech sound errors (phonologically) in their speech compared to normally reading adolescents producing phonologically complex multisyllabic pseudowords and phrases. In another study of Catts's (1989), he found indications of dyslexic subjects' inferiority to nondyslexic adults in repetitions of complex phrases; they were significantly slower in the task and made significantly more errors (mainly substituting sound segments for phonetically similar segments). Scanlon's results (1994) show that an 8 year old English speaking dyslexic girl also had considerably more difficulties with phonological accuracy as well as she had more variability in her performance compared to the control subject. The study by Scanlon is the only one of its kind to date in which acoustical measurements were used in the analysis of the speech of dyslexics. Although Scanlon measured syllable and whole word durations, she did not examine the segment durations individually and was not studying the quantity aspect of the speech. Therefore, this study also aims to fill in at least one part the information gap on the durational aspects of produced speech sounds in dyslexics.

1.5 Aims and main research questions

The major concepts and aims have already been touched upon but in order to gain an idea of the underlying aspects in the present study it may be advantageous to emphasise the main themes of the study. First of all, the aim is to elucidate the role of duration in the quantity distinction in the early language development of Finnish speakers. Apart from the normal language developmental aspect, impaired language development, specifically dyslexia, is studied. Therefore, the second aim is to investigate the role of duration in the quantity distinction as a possible early precursor for dyslexia. Thirdly, the quantity distinction is also examined in terms of dyslexic adults' speech perception and production. Finally, by studying the perception and production of dyslexic parents as well as those of control parents, the aim is to elucidate some aspects of the possible influence of parental input to the language development of children. These aims can also been seen in the following summary of the main research questions of the study:

Summary of the research questions:

1. Are 6 month old infants able to partition into categories words which vary in the duration of a single sound?

2. Do infants with high genetic risk for dyslexia differ significantly from those with no such risk in the perception of Finnish quantity at the preverbal stage?

3. Do dyslexic adults differ significantly from non-dyslexic adults in the perception of Finnish quantity?

4. Does duration in the productions of 18 month old infants with high genetic risk for dyslexia differ significantly from that of infants with no such risk?

5. Does duration in the production of sounds by dyslexic adults differ significantly from the that of non-dyslexic adults?

6. Are the quantity distinctions in the production of adults reflected in those of infants? And is there a difference in this respect between families with dyslexia and those with no language disorders?

7. If a difference is detected in any of questions 2-6, listed above, then what is the nature of that difference?

1.6 Outline of the study

The present study will proceed from this general introduction to a more thorough investigation of the subject at hand. The dissertation begins with a general framework for duration in the quantity distinction in Finnish. Also in Chapter 2 some aspects of the perception of duration are dealt with before describing Experiment 1 and 2.

In Chapter 3, previous studies on temporal processing in dyslexia are reviewed. After this the hypothesis of a possible temporal auditory perceptual deficiency in dyslexia is tested in Experiment 3 and 4 using the dyslexia projects' adults and infants as subjects.

In Chapter 4, the speech production of the same subjects is studied in terms of the quantity distinction. Previous studies on the durational dimensions of quantity production are reviewed as well as studies pertaining to dyslexics' abilities in the temporal aspects of speech production.

In Chapter 5, the evidence provided by the experiments of this study is collected together. In addition to the concluding remarks some suggestions for future research are given.

Before going any further, it should be emphasised that this study can be viewed as three individual sections dealing with related issues. Although it may seem as though this study consists of separate sections dealing with different aspects of the same theme, the intention is that it should also be viewed in its entirety, as a larger whole in which theoretical frameworks and experimental data compliment one another. Furthermore, some aspects of the information provided in these separate sections are necessary prerequisites for understanding and interpreting the results of the study.

2 DURATION IN QUANTITY CATEGORISATION IN FINNISH ADULTS

2.1 Purpose

The purpose of the two experiments described in this chapter is to find out the possible effects varying the duration of a single sound segment has on how Finnish adults categorize sounds into two phonological quantities in pseudowords. Furthermore, the information gained in these identification experiments provides a foundation on which the other auditory perceptual experiments of the present study, described in Chapter 3, are based.

Before proceeding to the actual experiments, a short review of literature is provided to facilitate the formation of a wider theoretical framework on which the hypotheses of the experiments are built. The role of duration in speech, particularly in the Finnish language, is reviewed. Since the experiments in this chapter are concerned with the perception of duration, some aspects of perception are reviewed including the manner in which durational aspects seem to be perceived in speech as well as what the smallest difference that can be perceived in terms of duration is. Before going into the more intricate details of the perception of duration a short review of the linguistic function of duration in language in general as well and in Finnish is provided next.

2.2 Duration in speech and its linguistic function in Finnish

Time is an integral part of spoken language. All spoken utterances are physically realised in time and, therefore, all utterances have certain durations, and the duration of segments, to the extent that they can be determined from coarticulation, can be measured. Some sounds are momentary by nature (flaps, taps, and semi-vowels), but most sounds, apart from having certain intrinsic durational characteristics, can be prolonged to the extent that speakers' physiological and aerodynamical limitations permit (Catford 1977, 196).

The extent to which durations can be modified in speech depends on many factors: the intrinsic duration of a sound[1], the quality and quantity of adjacent sounds, the position of a sound in a word and as a part of a larger utterance, the stress and length of the utterance, the physiological state of the speaker, the emotional intent of a speaker, the speech situation, the personal traits of the speaker and the speech tempo are among factors that can affect sound duration (Iivonen 1974b, 402; Klatt 1976, 1209; Wiik 1981, 104-106; Lehiste 1984, 96). As can be seen differences in duration are not only due to mere physiological constraints of sounds. Articulatory gestures can be consciously controlled and, therefore, it appears natural that duration is used in conveying meaning in speech communication.

The linguistic functions of duration are manifold. Klatt (1976, 1208), for example, includes in the linguistic functions of duration in English the following: duration is used in English as a primary cue in distinctions between intrinsically long and short vowels, phrase-final and non-final syllables, voiced and voiceless fricatives, voiced and voiceless postvocalic consonants, stressed and unstressed vowels and the presence or absence of emphasis. These are all functions on the segmental level but deliberate modifications of duration can also have their effect in larger units than that. For instance in Swedish, duration of adjacent vowels and consonants has a reciprocal relationship according to which a long vowel is followed by a short consonant and vice versa (e.g., Elert 1965, Lehiste 1970, Lehiste 1996). The above examples from Swedish and English show that the linguistic use of duration varies from language to language. Finnish, which is the language used in the present study, is one of the languages which makes phonological use of durational differences in the form of quantity.

The duration of sounds plays an important part in the Finnish quantity system (e.g., Lehtonen 1970, Lehiste 1970). Quantity in Finnish is realised in opposing segment durations, durations which are characterised as either short or long. There can be an endless amount of variation in durations but quantity categories or degrees, into which all the different physical durations are linguistically placed, are limited to two. In other words, if objectively measured there are myriad different durations of speech sounds but phonemically there are only either short or long segments in Finnish.

Naturally, duration cannot be the sole acoustic cue in quantity distinctions due to the complexity of spoken language. Careful

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1 Researchers over the years who have measured the durations of sounds have shown that they have intrinsic durations. Lehiste (1976) for example deals with the intrinsic duration of a vowel. The low vowels tend to be intrinsically longer than high vowels, because the production of the low vowels requires greater tongue and jaw movements and the biomechanical particularity is also more demanding compared to the production of high vowels.

investigations have shown that there may exist some quality differences as well (Sovijärvi 1938, Wiik 1965). For example, there is only a slight or a non-existent difference in quality between the long and short quantities in Finnish vowels. When a difference is at all detectable a tendency is that short vowels are somewhat lower and neutralised compared to long vowels. Hence, the quality differences are slight and it appears that Finnish speakers do not use quality differences as markers of phonological lengths (Lehtonen 1970).

Furthermore, the fundamental frequency, for example, of a segment may affect the way in which different degrees of quantity are processed in quantity languages like Finnish[1] (Lehtonen 1970, 22). One of the first indications of this can be seen in Malmberg's restricted data in which long vowels had a tendency to fall in pitch while short vowels were characterised by an initial rise in pitch which levels out towards the end of the sound (Malmberg 1949, 43-45). Lehtonen's results from a much larger corpus failed to demonstrate the tendencies found in Malmberg's study. Lehtonen (1970, 23) measured a rise in pitch at the onset of a vowel in syllables which received word-stress, and this pitch rise is obviously caused by stress. However, when the vowel in a stressed syllable was relatively short the tonal peak might have occurred after the end of the vowel rather than during the vowel as was the case with the long vowel. Similar tendencies could be seen in Wiik's (1988) data on some of the Finnish dialects as well as in Vihanta's (1988) less systematic data. It is plausible, as Aulanko (1985, 48) speculated when he observed similar tendencies in quantity related pitch changes in his data, that f_0 changes may make a vowel with a relatively short duration to be perceived as long. Consequently, available evidence strongly suggests that it is duration which is the main cue for the two different degrees of quantity in Finnish.

Typologically the Finnish quantity system is complex but highly extensive. Both consonants and vowels can be phonemically either long or short and virtually all sounds participate in the quantity distinction[2]. The occurrence of long or short sounds is not limited to stressed syllables, as is the case in, for instance, Swedish (Elert 1965). In addition, since there are only relatively slight intensity differences between stressed and unstressed syllables in Finnish, in contrast to the strong differences in the Germanic languages, there is no vowel reduction in unstressed syllables, which in turn facilitates the use of quantity also in unstressed syllables (Hirvonen 1992, 26). Phonemic length contrasts can occur in all positions with the exception of long consonants which cannot appear in word-initial and word-final positions. Thus, the following basic combinations of different

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1 In another quantity language, Estonian, change in pitch may influence the perceived duration and therefore the perceived length. Several researchers have suggested that the degrees of quantity are closely connected with stress in Estonian or that there are certain conditions concerning the duration ratios and the f_0 contours which have to be met (Fox and Lehiste 1987, 349; Eek 1994, 10, Hint 1997, 194-231).

2 Only /j v h d/ do not have the two quantity oppositions.

length contrasts are possible: (C)VCV, (C)VVCV, (C)VCCV, (C)VCVV, (C)VVCVV, (C)VCCVV, (C)VVCCV and (C)VVCCVV. With a change of quantity, words can be contrasted both lexically and grammatically (Engstrand & Krull 1994a, 81). This is illustrated by the following examples: the lexical meaning changes with different degrees of /t/ in the words *mato* 'worm' and *matto* 'carpet', and the grammatical use of the word changes with gradation[1] in the words *matto* 'carpet, nominative form' and *maton* 'carpet, genetive form'.

The domain of Finnish quantity appears to be the segment[2] (e.g., Lehiste 1965, Lehiste 1970, Magga 1984, Engstrand & Krull 1994a). This means that the two degrees of quantity can be combined relatively freely with no restrictions as to the length of the adjacent sounds. There appears to exist, however, several interesting relationships between segments (Wiik 1965, Wiik & Lehiste 1968, Lehtonen 1969, 1970): /CC/ is phonetically realised longer following /V/ than when it follows /VV/, and /C/ preceding a second syllable /VV/ is realised longer than when it precedes a second syllable/V/, and a second syllable /V/ is realised longer after a short first syllable than when it follows a long first syllable (Karlsson 1982, 151). The last two relationships are relevant to the present study. The latter relationship is pertinent here since the VCV structures are compared to the VCCV structures. Further, the relationship between the duration of an intervocal consonant and the length[3] of a second syllable vowel is of interest here. Since in Experiment 1 the duration of a word medial consonant is lengthened from the original VCV structure, the relatively long duration of the original word final vowel may be categorised as long together with the preceding consonant. If the first syllable consonant duration is used in this way as a cue to the categorisation of the following vowel, then the responses to the stimuli with increased duration of the consonant should show VCCVV identifications instead of VCCV identifications. Indeed, Lehtonen's data showed that there were some CVCCVV identifications in the cases in which the duration of C2 was lengthened from the CVCV structure but these identifications were not consistent across the stimuli. Lehtonen (1970, 174) drew the relatively strong conclusion, considering the relatively limited data of the identification tests in his dissertation, that the duration of a single consonant is not

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1 Consonant gradation is a grammatical characteristic of the Finnish language which occurs at the juncture between syllables. In consonant gradation the stops are made weaker: geminates simplify, in homorganing sonorant + stop clusters, the stop assimilates totally to the sonorant, *t* becomes *d*, *p* becomes *v* and *k* is deleted etc. (Nespor & Vogel 1986, 81).

2 The scope of quantity is also a language specific feature and it seems that it can be somewhere between the segment and the sentence. In Estonian it is the word and in Swedish the gramatical domain of quantity is the morpheme.

3 The term duration defines the physically measurable length of time determined in milliseconds whereas the term length is used to define the phonologically distinct category of the quantity degree, which can be either short or long in the case of the Finnish language.

systematically used as an identification cue for the length of the vowel following a consonant. Looking at his data, it seems that in the particularly strong case in which the relationship existed between the duration of the preceding consonant and the length of the word final vowel, the word final vowel was originally relatively long in duration compared to that in the other stimuli. The long duration of the V2 together with the long duration of the preceding consonant may have caused the subjects to identify it as phonemically long. It could be that in certain conditions taking into account the sound environment as well as the word structure that this kind of reciprocal relationships exists at least in some individuals. Therefore, this aspect is also investigated in the present study, although with very limited linguistic material.

A characteristical attribute of quantity is its relativity. Listeners attend to the function of durations in a given context and the absolute durations are viewed in relation to other sound durations and overall speaking rate (Lehiste 1970, O'Dell 1985a & 1985b). In Lehtonen's study (1970), for instance, the measured durations of phonemic lengths in the CVCV structures in comparison to the CVCCV structures revealed that a short segment in one context can be twice as long as another short segment in another context. Essentially, however, so called long segments seem to be approximately twice as long in duration to their short counterparts in the same position in a word (Lehtonen 1970, 33). Considering the relative nature of the phenomenon, it is important to make a distinction between the concepts of physical quantity and subjective judgment[1] of quantity, as Lehtonen (1970, 6), for instance, does in his dissertation. The physical quantity or duration is the length of time which can be objectively measured from speech sounds. The subjective linguistical judgment of quantity in this case refers to the subjective impression of the perceived dimension of time. In communication listeners hear and evaluate the degrees of quantity in a particular context according to their own subjective scale of what is long and what is short (Lehtonen 1970, 14). In addition, as Lehtonen (1970, 17) points out, even when a listener attempts to evaluate speech sounds audibly by duration, the structure of language and experience with a specific language always affect judgment. Presumably everyone has his or her own code in interpreting the durational differences linguistically according to his or her own linguistic experiences with that particular language.

The subjectivity of quantity degrees in spoken language is also apparent in some observations of various dialects of Finnish (Wiik & Lehiste 1968, Wiik 1985). Variation in segment durations within one quantity degree is large depending for instance on the many conditioning factors on durations which were listed earlier. Notwithstanding the overall observation that the two degrees of quantity are kept apart by clear distinctions of durations in Finnish speech (Engstrand & Krull 1994a), a

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1 The subjective quantity -concept originates from Malmberg (1944, 28) who defined the concept in question to be a linguistically relevant quantity. Lehtonen's interpretation of the concept is more specific and more appropriate in terms of Finnish quantity emphasising the subjective judgments of perceived durations against the time dimension.

wide variety of durations is apparent in different dialects in certain word positions. An interesting dialectical subphonemic durational phenomenon which was already mentioned is the so called half long vowel in word final position in CVCV types of structures. Phonemically this segment is short but its duration can be twice as long as that of the short vowel in the CVCCV structure. According to Wiik's data[1] (1985) the word final vowel is always relatively long in duration in CVCV structures compared to CVCCV structures in all speakers of Finnish but it is the extent to which it is lengthened which differentiates speakers of various dialects. Thus, the paradigmatically defined half long vowel (i.e., what is the percentage of V2 in CVCCV structures compared to that in CVCV structures) can range from just over 100 % to approximately 300% (Wiik 1985, 286). The half long vowel is realised in many different geographically dialects to various extents. In brief, suffice it to say that the main areas where the longest half long vowels are the areas of the South-West Finland, Torniojokilaakso, Savo and Central-Kannas, and the areas of shortest half long vowel are in South-Ostrobothnia and Häme (for more details see Wiik 1985, 286-315).

Another dialectical phenomenon involving changeable duration is gemination, both primary and secondary types (of gemination). In both of these sound changes a single consonant has a tendency to be lengthened: In primary gemination consonants following short stressed syllables become lengthened either before a long vowel (*kallaa* which in standard Finnish is *kalaa* 'fish', partitive singular) or a diphthong (*kuvvailla* for the standard *kuvailla,* 'describe') whereas the secondary gemination can occur in consonants preceding long vowels after a long stressed and an unstressed syllable (*kävellöö* which in standard Finnish is *kävelee* 'walk', sing. third person present)(Palander 1987, 245). The lengthened consonant may serve as a cue for the following vowel by adding the original CVCV/CVCVV distinction and thus having the contrast between CVCV and CVCCVV (Lehtonen 1970, 174). The gemination phenomenon is widely spread but as Palander (1987) and Nahkola (1987) both note, although the spreading tendency is still continuing it appears that people limit the use of the gemination to informal contexts. This is an important factor for studies like the present to notice since it is likely that the experimental situations are formal and thus bring to the surface the more formal speech code of the subjects. As was mentioned earlier, the gemination phenomenon is dialectical, and as Lehtonen's (1970, 174) empirical examination of standard Finnish seem to show the duration of a single consonant following a short syllable is not systematically used as an identification cue for the length of the vowel following the first syllable consonant.

1 It has to be noted that Wiik's data should be treated with some caution since it is miscellaneous in terms of the lengths of the words, tempo of the speakers and position in the sentence. These factors have to be taken into consideration in the interpretation of his results. The fact that he also analysed perceptual distributions of the segment durations provides limitations to the temporal variability of the data. Furthermore, his data is extensive and deals with natural conversational speech which as such provides a good picture of the phenomenon in natural settings.

Although the issue of subjectivity in quantity degrees has been acknowledged, the issue of individual differences has not been specifically studied in this context[1]. In a recent study by Aaltonen, Eerola, Hellström, Uusipaikka and Lang (1997) the results on synthesized vowel quality categorisation (between /y/ and /i/) showed that there were clear differences between native listeners of Finnish in the categorisation function. The location of the boundary between the stimuli and the phoneme boundary width varied greatly between a relatively small number (13) of subjects. The results gave some indications of possible group differences between the subjects which Aaltonen et al. (1997) named as "good" and "poor" categorisers. Interestingly, Aaltonen et al.'s results indicated to some extent that categorisation was more inconsistent than discrimination within subjects. Considering the flexibility of durational dimensions and the relative nature of quantity degrees as well as dialectical tendencies in the use of duration it can be hypothesized that there may be individual differences in terms of the quantity categorisation investigated in the two experiments.

2.3 Perception of duration

The experiments of this chapter involve the perception and identification of speech sounds with only the durational parameter changing between stimuli. Researchers found already in the 1950's in an attempt to find possible primary cues in speech perception that changing a single acoustical dimension in regular increments can have a radical effect on the labelling function of speech sounds (Liberman, Delattre & Cooper 1952, Lisker 1957, Liberman, Harris, Hoffman & Griffith 1957). The labelling function typically changes abruptly in a small number of increments within a continuum. Liberaman et al. (1957), who were the first to learn about this perceptual phenomenon, called it categorical perception. Categorical perception means that listeners have a tendency to perceive a phonetically-relevant acoustic continuum discontinuously, i.e. a continuum of sounds is partitioned into discreet categories of sounds by the auditory system (e.g., Burnhamn, Earnshaw & Clark 1991, Schouten & van Hessen 1992). Furthermore, according to the original definition listeners can discriminate between stimuli only to the extent that they identify the two stimuli as different. Thus, because the auditory experiments here are identification tasks the results should indirectly provide information also on the discrimination skills of the listeners.

It appears that in the speech context duration is also perceived categorically. In the present experiments the durational variation is located in a silent interval of stop occlusion. There exists an ample amount of evidence on the effect of silence duration in phonetic perception. For

1 Lehtonen (1970) acknowledges the individual differences but specifically states that his study does not address this issue.

instance, when silence is inserted between the /s/ and /l/ of 'slit' it will cause the word to be heard as 'split' (e.g., Bastian, Eimas & Liberman 1961, Baumrin 1974, Fitch, Halwes, Erickson & Liberman 1980). Also, differences in the duration of silence sometimes serve to cue the voiced-voiceless distinction, as in the case when duration is manipulated in the word 'rabid' changing it to 'rapid' (e.g., Liberman, Harris, Eimas, Licker & Bastian 1961).

As can be expected Lehtonen's (1970) studies on quantity also reveal that the durational changes of a silent stop closure are perceived categorically. In terms of categorical perception, the particular interest here is the location of the boundary between two quantity degrees when only the primary cue of the distinction is changed. According to Lehtonen's (1970, 173) results on lengthening the original word *mätä* the boundary was located at approximately 220 msec (it was approximately the same with other stop consonants as well). As has been discussed earlier, the many conditioning factors affect the particular location of the boundary and therefore the results of previous studies with different stimuli cannot provide specific information on the categorical perception of the stimuli used in these experiments. The location of the category boundary in the present study, however, is particularly significant since the results of these experiments dictate the design of the other perception experiments of the present study.

In designing as well as interpreting the results of the present experiments, one of the necessary facts to be considered is what is the smallest difference in duration or a just-noticeable difference (JND) that listeners are capable of perceiving. Lehiste (1970) described a number of studies which specifically examined JNDs for duration discrimination. As could be expected, one of the findings was that there is no absolute audible threshold in duration but rather it changes according to the context. Thus, Stott (1935) and Henry (1948) discovered that the durations which are above the audible threshold fall between 10 to 40 msec in the stimulus duration with a stimulus range of 30-300 msec. Ruhm, Mencke, Milburn, Cooper, and Rose (1966) found noticeable smaller JNDs to the order of 1.7 to 2.6 msec with a stimulus duration ranging from 40 to 100 msec. This JND is approaching basic psychophysical limits for duration discrimination (Abel 1972). According to Abel's results (1972) the JNDs in duration discrimination of low-pass filtered noise bursts at a variety of frequencies was between 5 and 40 msec with a stimulus duration ranging from 50 to 400 msec. On the basis of these results it is relatively clear that the longer the reference duration the longer the JNDs. It should be noted that all these studies on JNDs have been conducted using nonspeech stimuli. The relation and relevance of results gained using nonspeech stimuli to speech perception can be questioned. Speech stimuli are highly complex and a variety of factors (e.g., intensity, f_o, rapid transitions) may play a significant role in the perception of one acoustic dimension. Speech is, therefore, perceived in a different manner than other acoustic signals (Liberman 1982). On the other hand, the perception of speech is based on the same auditory system as nonspeech and JNDs in either mode could be based on some basic audible threshold with the same psychophysical perception limits.

A more relevant study of JND involving speech stimuli is the study by Fujisaki, Nakamura, and Imoto (1975) in which the discrimination of stop consonants among other sounds with varying durations was studied with a small number of subjects (5). They discovered that when a segment duration was about 100 msec the JND near a phoneme boundary was 11 msec when the stimuli were presented individually, and 8.9 when the stimuli were presented within a sentence frame. Klatt and Cooper (1975) criticised these and other studies of JNDs for presenting the stimuli many times to the subjects which would enable the building up of strong psychological reference patterns for the reference stimulus. In Klatt and Cooper's experimental design the frequency of the stimuli presentation was controlled to be low which resulted in a JND of 25 msec. Klatt (1976, 1219) concludes that since his results and others to some extent seem to follow Weber's law[1], it could be said that changes of about 20% or more may serve as primary perceptual cues in differentiating a speech stimulus from another. Naturally, if employing a stimulus increment of lower than the audible threshold, the possible difference found between subjects or subject groups cannot be linguistically significant. In the present study the stimuli is constructed by initially changing the duration of the original stimuli by 20% which in practice means that the stimuli continuum is made up of steps of 20 msec. Such a large increment can be considered to be over the JNDs and, therefore, the possible differences found in subjects in the two experiments described next could be considered to be linguistically significant, which in turn facilitates the interpretation of the results gained.

2.4 Experiment 1

2.4.1 Research questions

The first experiment was designed to investigate how varying the duration of a stop closure affects the identification of pseudowords in Finnish adults. Earlier experiments (e.g., Lehtonen 1970) have indicated that the mere durational alteration of a stop closure may serve as a cue for the quantity categorisation of the word medial consonant in Finnish words. Experiment 1 was designed to gain answers specifically to the following questions.

1. How is the pseudoword *ata* with a stop closure of varying duration identified by adult native speakers of Finnish?

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1 Weber hypothesised that the ratio between the stimulus increment and the reference stimulus is constant. Actually it appears that the ratio does not remain completely constant. The Weber ratio is the ratio $\Delta T/T$, that is, change in duration over reference duration (Lehiste 1970, 11).

2. Are Finnish speaking adults able to categorise words into two quantity categories on the bases solely of the duration of a closure?

3. If the identification function is categorical what is the location of the category boundary in the durational continuum? And what is the extent of the bandwidth between the categories?

4. Are there individual differences in the location of the category boundary and in the extent of the bandwidth?

5. Does varying the duration of a stop closure affect the identification of other sounds in the word?

The answers to these questions are sought in the sections *results and discussion* (36-43), after a description of the methods used in the experiment.

2.4.2 Method

2.4.2.1 Subjects

Thirty two undergraduate students, naive to the purposes of the study, from the University of Jyväskylä served as listeners in the experiment. They ranged in age from 21 to 30 (x = 23). Half of the subjects were males and the other half were females. They were all native speakers of Finnish and declared themselves to have no language, speech or hearing impairment. The geographical dialectical background of the subjects was heterogeneous: approximately 22 percent of the subjects originated from the region of Ostrobothnia (7), 19 percent from Central Finland (6), 19 percent from Häme (6), 16% from Savo (5), 9% from South-West Finland (3), 6% from Oulu (2), 6% from Uusimaa (2) and 3% from Lapland (1). None of the subjects had participated in pshychoacoustical experiments before.

2.4.2.2 Listening material, instrumentation and procedure

A minimally differing set of ten stimuli were constructed from the original *ata* word. The pseudoword *ata* was chosen as a point of departure mainly taking into consideration the other experiments of this study as well as intended future studies. The first criterion in the selection of the stimuli continuum was that the words should be possible Finnish words (i.e., sounds as well as a phonotactical composition should be Finnish) but still the words should have no meaning to Finnish speakers. This was done in light of the dyslexia studies in which pseudowords had been reported to be particularly difficult for the dyslexics to process (Stone & Brady 1985, Snowling, Goulandris, Bowlby & Howell 1986, Taylor, Lean & Schwartz 1989, Brady, Poggie & Rapala 1990, Gathercole & Baddeley 1993, Hansen & Bowey 1994, Apthorpe 1995), and in this way perceptions of pseudowords may serve as good indicators of processing problems in dyslexics. The second criterion was that the words should be as short as possible while still exemplifying the two quantity categories of Finnish. This meant that the words had to have two syllables. Again, shortness was aimed for because infants were involved in the later experiments. The third criterion was that the words should consist of sounds that are known to be among the first to be acquired by young infants. The open back vowel is one of the first vowels in infants' speech (e.g., Oller 1980, but see Iivonen 1993 who presents counter evidence), and was, therefore, chosen for the stimuli here. Also stop consonants are reported to be among the first sounds (e.g., Iivonen 1993) and the alveolar stop is often recognized from the speech of infants as the first consistent adult like stop sound (Iivonen 1993, 1994). In addition, the use of a stop sound was ideal here since stops are relatively easy to distinguish from the graphical representations of the acoustical signal, and more importantly, since they include a clearly distinguishable period of occlusion which is silent in the case of voiceless stops. This means that the occlusion of the sound is first of all easy to recognise and secondly easy to manipulate synthetically.

Stimuli for the experiment were constructed in the following manner. The speech of a Finnish speaking female was recorded as she read words and sentences. Twenty *ata* words were included in a text as well as three short sentences read several times in a random order. The sentences were the following "Sano ata tässä" ('Say ata here'), "Sano ota tässä" ('Say take here') and "Hän sanoi äidillensä: Minä en ota sitä ('She said to her mother: She said to her mother: I won't take that.'). She was instructed to speak the words as clearly and as quickly as possible so that her intonation and speech tempo would be as close to her normal speech style as possible. In addition, she was instructed to speak in the way she would speak to young infants since the same stimuli were used in the other experiments of the study involving young infants. The sentences which formed a point of reference were used in an attempt to ensure that the speech of the female would be more natural in tempo than if she had read a list of words, because speakers usually speak faster and enunciate the words less carefully if they speak whole sentences (Ladefoged 1975, 166; Shoup and Pfeifer 1976, 205). For the test word *ata*, the recorded sample chosen was that which was nearest in the absolute durations as well as the relative durations of the sounds to the words *ata* and *ota* spoken within a sentence frame. Temporal aspects of stimuli are paid special attention to here since durational aspects of the speech are under investigation. The use of natural speech was favored over synthesized speech in order to bring the experiment as close to natural communication as possible.

stimuli	ata 1	ata 2	ata 3	ata 4	ata 5	ata 6	ata 7	ata 8	ata 9	ata 10
occlusion in msec	95	115	135	155	175	195	215	235	255	275

FIGURE 1 The stimuli continuum employed in the perception test in Experiment 1. Duration of the silent closure stage of the word medial dental stop was augmented in stepwise fashion by increments of 20 msec. Natural speech sounds were used as stimuli. The original stimulus was taken from the speech of a female producing the pseudoword *ata*. Altogether 10 stimuli were constructed from the stimulus *ata*1 ranging in total duration from 300 to 480 msec, and the impression of the perceived stimulus shifted from *ata* to *atta*.

The naturally produced *ata* stimulus was used as a starting point from which the rest of the stimuli were constructed (the continuum is presented in Fig 1). The whole set of stimuli formed an artificial continuum with a highly restricted and narrowly defined set of conditions for the discrimination of stimuli. In the continuum only one acoustic cue, namely duration, was varied in stepwise fashion; all other acoustical dimensions, such as fundamental frequency and intensity, were held constant. The original *ata* formed the first stimulus in the continuum. Then another nine stimuli were constructed by adding 20 milliseconds of silence at the time in the middle of the silent occlusion. The impression was that the perceived stimulus shifted from *ata* to *atta*. The durations of the sounds were the following: the first vowel was 72 milliseconds, the occlusion of the word medial stop 95 and the following vowel 133 milliseconds. The total duration of the original word was 300 milliseconds. The segmentation conventions for the phonetic durations are the following (these are also illustrated in Fig. 2):

VOWEL 1 /a/ = The duration of the vowel preceding the word medial stop, was measured from the point at which the voicing began to the beginning of the occlusion of the following consonant. Also the weak glottal stop[1] (15 msec in duration) at the beginning of the word was included in the duration of the first vowel.

CONSONANT /t/= The duration of the occlusion of the stop. This was measured from the point at which the occlusion of the stop begins (voice offset time, i.e., the time interval measured from the beginning of the occlusion to the point at which voicing of the preceding sound ceases, was included) to the beginning of the release of the stop.

1 The glottal stop is typical at the beginning of the word which begins with vowel. An attempt was made to avoid the glottal stop at the beginning by having the test word in the middle of a sentence frame. However, all the productions of the female had the glottal stop at the beginning.

VOWEL 2 /a/ = The duration of the vowel following the word medial stop, was measured from the point at which the release of the stop begins to the end of the signal in which the voicing ends.

The primary purpose of the above segmental definitions is not to provide a close correspondence to discrete phonetic events but rather to ensure reproducible measurements. On the whole, the segmentation of the experimental parameters, however, proved to be straightforward. Concerning the duration of the occlusion, there was an unambiguous point in the spectrogram indicating the beginning of the occlusion, and, in addition to this, there was a significant change in the intensity curve.

For the recording of the original stimuli a Sennheiser condeser Microphone (MKE 4032 U3) and a digital audio tapecorder (Sony A8) were utilised. The audio data were acquired using the SoungDesigner[1] and edited with the Signalyze[2] speech analysis and editing software[3] on a Mac IIci computer. A 22 kHz sampling frequency was used for digitizing the female's utterances. The speech signal was low-pass filtered and a 16-bit quantization was used during storage. Principally, wide-band spectrogram presentations of the speech signal were used, along with auditory information, to gain information about the temporal features of the sounds, and only in ambiguous cases was the information of the intensity curve taken into account in analyzing the speech of the subject. Illustrations of the segmentation criteria are given in Fig. 2, in which closure duration of the stop and preceding and following vowel duration are indicated. The duration of the vowel preceding the stop was 72 msec and that of the vowel following the stop was 133 msec. The duration of the occlusion was 95 msec. Members of the continuum differed in stop occlusion duration, which ranged from 95 msec to 275 msec in 10 steps. The total duration of the stimuli varied from 300 to 480 milliseconds. These computer-assisted measurements may differ from some previously used manual measurements from sound spectrographs, and this fact should be taken into consideration when comparing the results of the present study of segmental timing of the Finnish stops to some studies executed earlier[4].

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1 SoundDesigner® is an audio editing software and hardware package for the Machintosh that can be used for data acquisition from DAT recorders. SoundDesigner® is a product of the DigiDesign® company.

2 Signalyze® is a product of the InfoSignal® company and is a speech analysis program for the Machintosh with spectral analysis tools and a set of signal manipulation tools.

3 The Signalyze® program enables sound waves from the speech signal to be presented graphically; i.e., it translates the sounds into visual representations, showing the component frequencies of the sounds across time, in the same manner as a spectrogram. In addition, the spectral analysis of the speech analysis program is able to present an intensity curve of the speech signal.

4 For instance, in studies carried out by Lehtonen (1970, 47) the acoustic events were measured manually and the results were rounded off to the nearest five

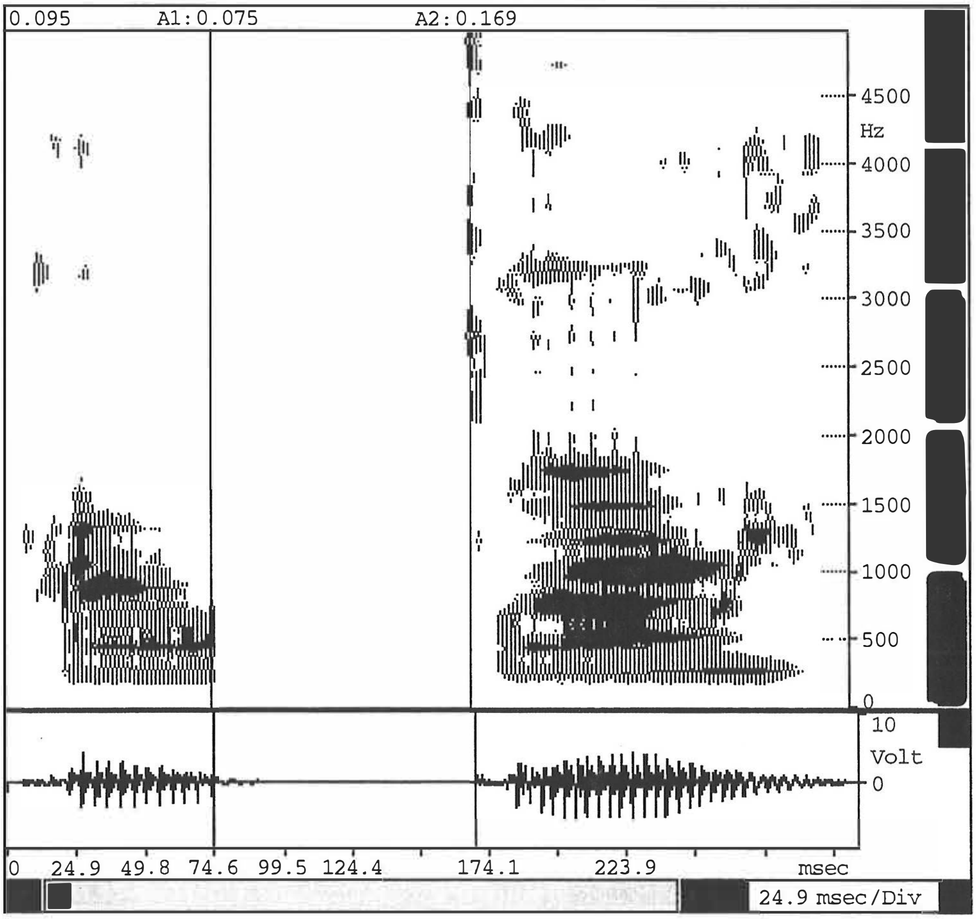

FIGURE 2 Speech wave and spectrogram representations of the naturally produced pseudoword *ata* illustrating the segmentation conventions employed in the present study. The graphic illustration of the word clearly shows the silent gap in the stop. The duration of the occlusion is 95 msec. The preceding vowel is measured to be 72 msec including the short glottal stop at the beginning of the word. The word final vowel is measured from the beginning of the stop's release whose duration is 133 msec. The first vertical line in the picture shows the end point of the first vowel which is also the beginning of the occlusion. The second vertical line marks the end point of the occlusion and at the same time the beginning of the word final vowel. The graphic illustrations demonstrate that the pseudoword was produced with an emphatic stress on the final syllable. This is shown as a relatively large degree of amplitude (darker areas) in the second syllable. This may have affected the duration of the word final vowel since the more emphasised sounds can sometimes be slightly longer in duration than unemphasised versions of the same sounds in the same context in Finnish (Lehiste 1970, 36).

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milliseconds. In the present study, computer assisted measurements were rounded off to the nearest millisecond.

The experimental stimuli set was tape recorded using a high quality cassette deck. All ten stimuli were presented ten times with an interstimulus interval (offset to onset) of five seconds. These 100 experimental stimuli were randomised and divided into five blocks of 20 stimuli each with a ten second time interval between blocks. In addition, two randomly chosen stimuli and the original *ata* stimulus were presented at the beginning of the test as extra stimuli. These additional words were not considered in the following analyses. The extra stimuli were added in order to minimize any inconsistencies at the beginning of the test, caused by the unfamiliarity of the test conditions.

All 32 subjects took a 100-item identification test individually in a small sound treated room. They listened with high quality attenuated headphones to stimuli presented at a comfortable listening level. Listeners were told that they would hear 100 words presented one at a time and their task was to write down what they had heard on the answer sheet provided. They were instructed to listen to each stimulus carefully because of the shortness of the test stimuli and since the items may be very similar to one another. They were told to answer according to their immediate impression of each test item and to respond in writing to every stimulus and not to leave any answers blank. The subjects were informed that there was a five second gap between the stimuli during which they were to write their impressions. Also they were informed that after each twenty items there would be a longer ten second gap in order to facilitate the matching of the test stimulus they were hearing with the appropriate gap in the answer sheet. The whole listening task took approximately 14 minutes to complete including the oral instructions.

2.4.3 Results and discussion

All the test words were identified by all the subjects, making a total of 3200 identifications. In general, the results indicate that the stimuli were identified in principle in the same way across the thirty-two Finnish speaking subjects: variations in the closure duration of *ata* resulted in mainly *ata* and *atta* identifications. The following identifications were made: in 96% (3076) of the responses stimuli were identified either as *ata* or *atta*, 2 % (78) of the responses were *attaa* identifications, 0,7 % (31) *ataa* and 0,5 % (15) *ota* ('take') identifications.

The responses in the identification task revealed that the quality of the sounds in the stimuli was perceived relatively unambiguously. Obviously the sounds in the stimuli were clearly perceptible to these Finnish speaking subjects, and the fact that the stimuli were not meaningful words in Finnish did not affect the perception of the quality of the sounds. Only one of the subjects systematically identified a part of the stimuli as the Finnish word *ota* by changing the degree of openness of the word initial back vowel: all the stimuli with the short quantity degree in the word medial consonant were identified by her as *ota,* but all the stimuli which she perceived as having long quantity were identified by her as *atta*. One explanation for this behavior could be that in this case the listener was unable to detach herself from the way in which speech stimuli is usually perceived in natural communication, i.e., normally speech sounds are utilised to convey meaning and, therefore, listeners attempt to construct a meaning out of the sounds they perceive. Interestingly, she did not perceive the stimuli with longer closure durations as meaningful Finnish words, like for example *otto* 'withdrawal or take, or a name of a male" (*otta* is not a meaningful word in standard Finnish, as is the case with the other possible combinations of the word structure with different back vowels). Perhaps, if in the shorter stimuli the word initial vowel was unambiguous enough to this particular subject to facilitate the perception of /o/ instead of /a/, then in the longer context the word structure together with the seemingly unambiguous qualities of the other sounds prevented meaningful identifications of the longer stimuli.

All the responses in the identification task demonstrate the clear manner in which the changes in mere closure duration affect the perception and categorisation of sounds. It should be noted that since all subjects' responses display quantity degree changes (even in the ota-atta responses), all the identifications regardless of the quality of the identifications were included in the categorical analyses. The subjects' responses have been plotted in Figure 3 concerning *ata-atta* identifications in Experiment 1.

It is evident that the durational changes of a stop closure are perceived categorically by Finnish speakers. The physically shorter durations of the continuum are categorised into the short quantity category and physically longer durations are categorisied into the long quantity category. This is apparent from the written responses since in the Finnish orthography the short quantity degree is written with one letter and the long quantity is written with two identical letters.

The crossover point of the two categories is approximately 140 msec in this data: the closures shorter than 140 msec were identified as short and the closures longer than that were identified as long. This phoneme boundary cannot be directly compared to any other data with different stimuli since research on categorical perception has shown that the location of phonological category boundaries on physical stimuli continua is flexible depending on, for example, the context provided by other stimuli in a test, and the internal structure of a single speech stimulus as well as the linguistic experience of listeners (Repp and Liberman 1987, 89). The same to some extent applies to the bandwidth of the category boundary. This was determined by arbitrarily assigning the level of 80% of the changes to be the limits of the bandwidth. The area in this data in which the subjects were most uncertain about the quantity of the word medial consonant is approximately 58 msec in duration. In Lehtonen's (1970, 188) study the duration of the bandwidth[1] was on average 87 msec with varying stimulus types. Although the bandwidths are not comparable for the above

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1 Also in Lehtonen's study the bandwidth between categories was defined by an 80% level of changes.

mentioned reasons[1], it appears that the stimuli in the present experiment were categorised relatively uniformly since the bandwidth was narrow. But as has been stated earlier the bandwidth and especially the theoretical categorical boundary here mainly serve as points of reference for the designs of Experiments 3 and 4.

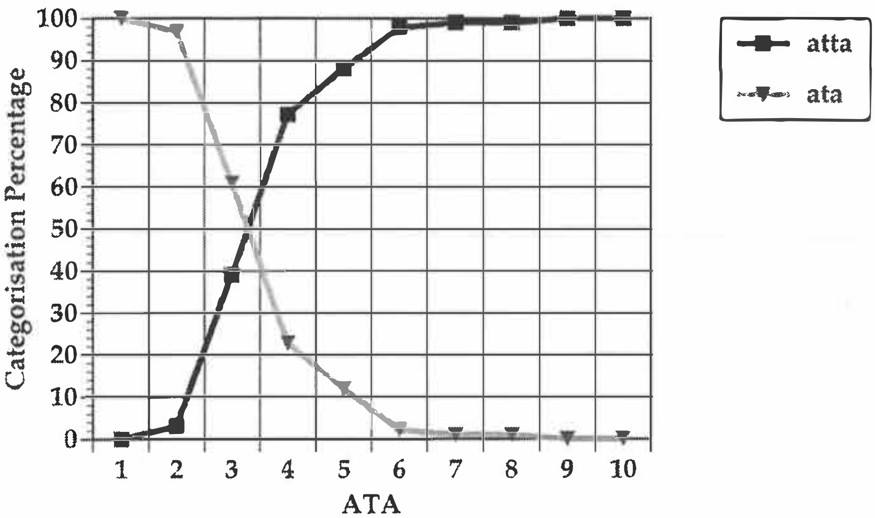

FIGURE 3 The categorisation function for the stimuli continuum constructed from the pseudoword *ata*. The numbers on the abscissa denote the stimuli 1 to 10 from the *ata*-continuum. The duration of the word medial consonant increased from the stimulus number 1 (which was the original stimulus from which the rest of the stimuli were constructed) to number 10 by 20 msec steps. The percentage of responses is shown on the ordinate. The crossing point of the two curves indicates the category boundary which in these data is located between stimulus 3 and 4.

The results indicate that varying duration of a stop closure does not appear to affect the categorisation of the surrounding sounds. This is indicated by the consistent identifications of *ata* and *atta*. Nevertheless, there were a small amount of responses in which the word final vowel was identified as having the long quantity. All the *attaa* and *ataa* identifications were made by two subjects. Most of these identification (72 %) in which the word final vowel was categorised as long were made by a male subject (number 6; his categorisation function is presented among the other individual responses in Figure 4) and the rest of these identifications were made by one female subject (number 11).

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1 Another divergence between the present study and that of Lehtonen is that he presented the stimuli in the order of durational changes between the stimuli whereas here the stimuli were presented in a random order (Lehtonen 1970, 156).

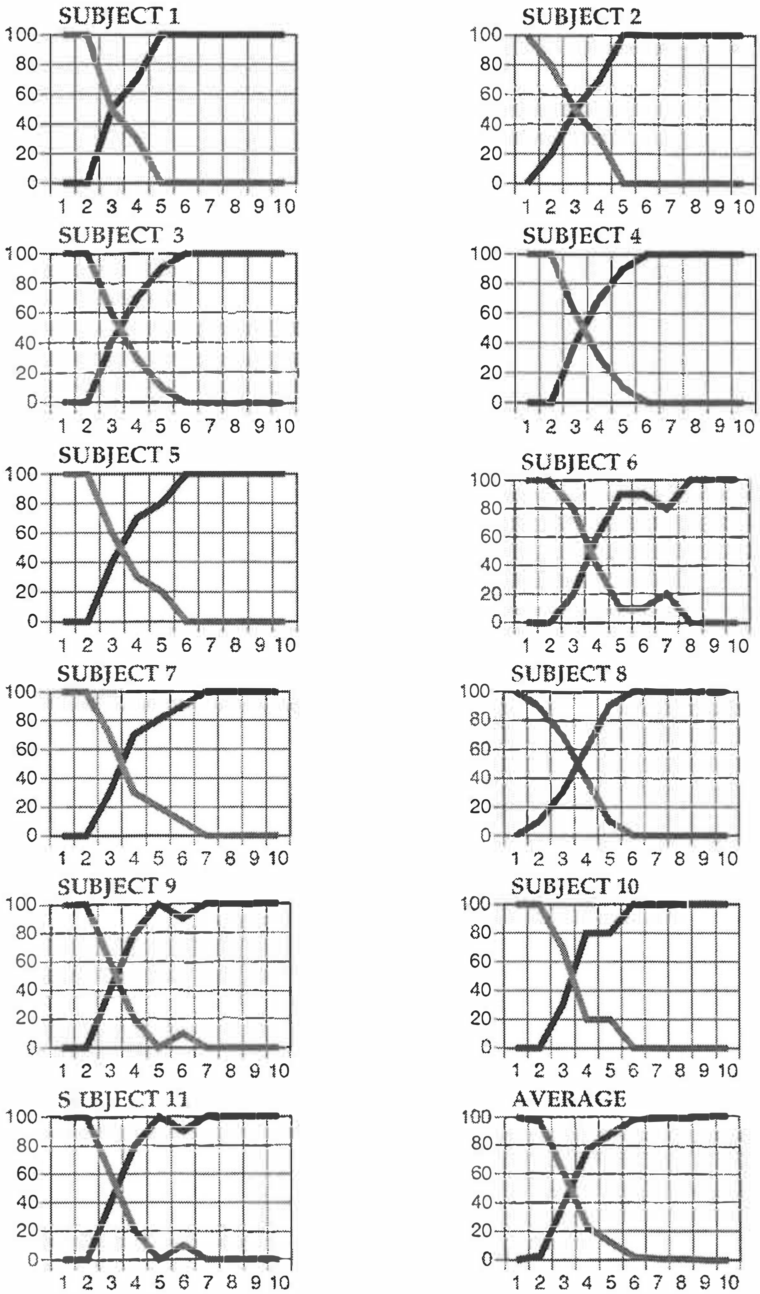

FIGURE 4 Categorisation functions of individual subjects in Experiment 1. The black line shows the *atta* responses and the grey line denotes the *ata* responses. The 10 stimulus items are shown on the abscissa, and the percentage of responses is shown on the ordinate. The last graph in the right column shows the mean average of the responses.

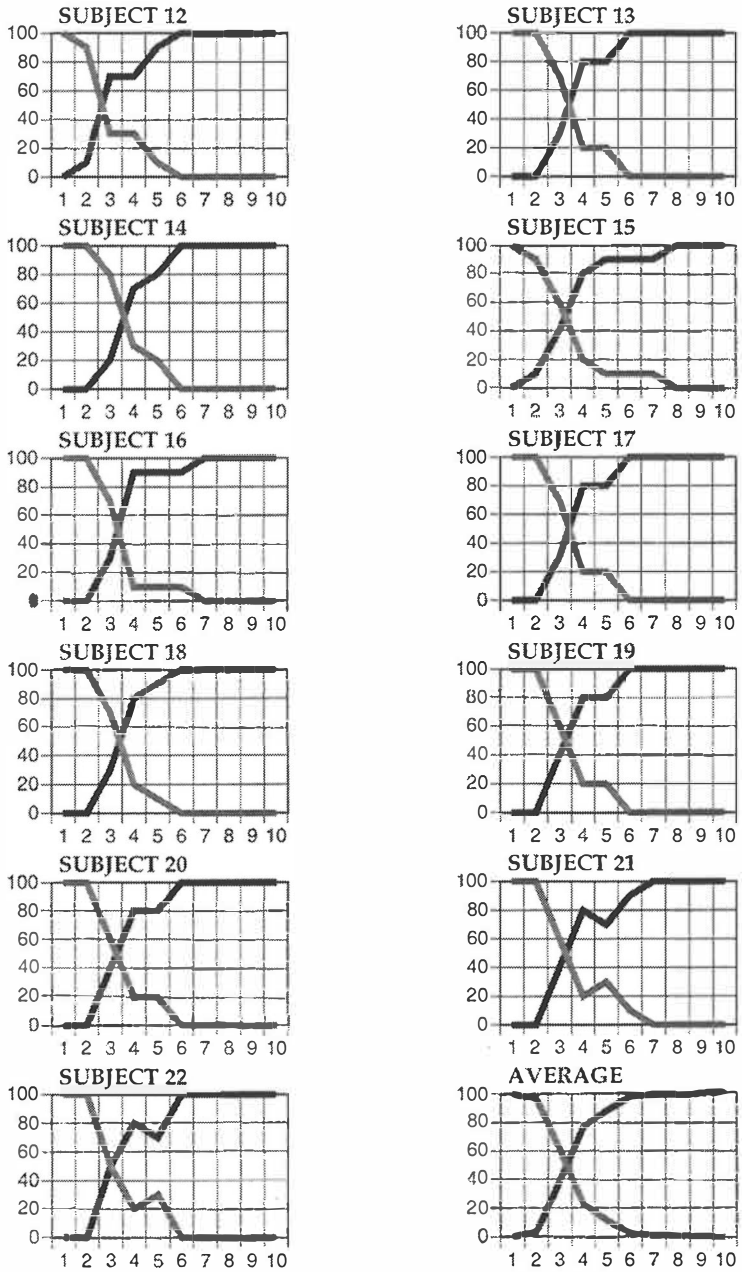

FIGURE 4 (Continues)

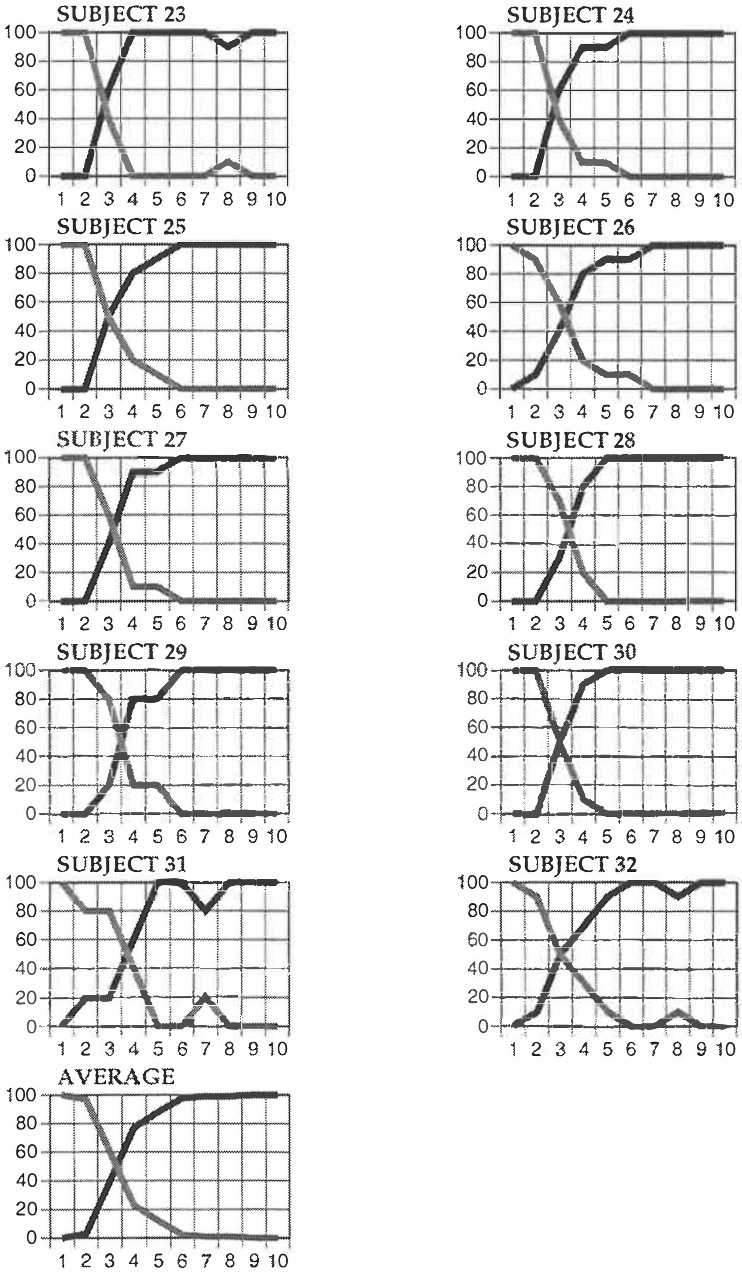

FIGURE 4 Continues

The male subject made all of the *attaa* identifications in the cases in which one of the longest stimuli was presented and all of the *ataa* identifications in response to the shortest stimuli: *attaa* was identified every time except four times when *ata 5* to *ata 10* were presented (the exception being *ata 5* once, twice *ata* 6, and once *ata* 8), and twice in *ata* 4; and *ataa* identifications were made at seven of the *ata3* presentations, 9 out of 10 cases of *ata* 2 presentations, and 5 cases of the *ata 4* presentation. Thus, it appears that the duration of the closure affected relatively consistently the judgments of this subject on the word final vowel length: the longer the closure duration the more likely the word final vowel was identified as long. The identifications of the long word final vowel are not predictable in this case from the geographical dialect of the male. He has lived all his live in Jyväskylä, and according to Wiik's (1985) geographical analysis of the existence and extent of the half long vowel, Jyväskylä belongs to an area in which relatively long second syllable vowels are used. It should be noted that he was very eager to know the "correct" results of the test as well as what was the aspect that was studied in this experiment. He also mentioned that he had tried to figure out the system behind the test while taking it. His inclinations and adopted strategy may well partly explain his behavior in this experiment.

The female's *ataa-attaa* responses were in the following cases: *attaa* responses were sporadical when *ata 6* to *10* were presented (4 cases of *ata 6*, 2 cases of *ata 7*, 5 cases of *ata 8*, 3 cases of *ata 9*, and 6 cases of *ata 10*) and her *ataa* responses were in 3 of the *ata 4* presentations, 3 in *ata 3* presentations, and 4 in *ata* 2 presentations. As in the case of the male, the only stimuli which were never identified as having the long word final vowel were the stimuli *ata 1*, the original *ata* stimulus. The female subject in question originates from Helsinki. Her dialect could partly explain these responses since the half long vowel can be relatively short in her dialectical[1] environment (see Wiik 1985).

As can be seen, the amount of responses with the long quantity degree in the word final position is small. This evidence supports Lehtonen's (1970) general observations on his identification test using Finnish words as stimuli. As was mentioned earlier, Lehtonen (1970, 174) found that the lengthening of a word medial consonant had an effect on the following vowel in so far as the quantity degree of the word final vowel was identified as long, but this was not a consistent trait among different stimuli. Correspondingly, here it appears that the duration of the word medial consonant does not straightforwardly affect the length of the following vowel. The present results contradict Lehtonen's interpretations in one respect, however. Lehtonen (1970, 175) speculated that the reciprocal relationship displayed specifically in one of the stimuli in his study may have been due to the fact that the original duration of the word final vowel was relatively long when compared with that of the first syllable vowel. Here, however, the durational ratio of the half long vowel was even slightly longer (0.54, in Lehtonen's study it was 0.55), and yet the relationship in question is not evident in the present data. Perhaps the

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1 Unfortunately, the dialectical backgrounds and actual dialects spoken by the subjects were not investigated in this study and, therefore, it is unknown what is the effect of various dialects on the identification test.

structural environment and general sound environment together with the intrinsic durations of the sounds can sometimes cause this reciprocal relationship even with artificial stimuli, but according to the empirical evidence this relationship does not appear to be systematic by any means.

The analysis of the individual subjects' identification function revealed that the categorisation of the different stimuli did not vary drastically between individuals. In fact the individual data are relatively uniform in which most of the subjects located the category boundary between the stimuli *ata 3* and *ata 4*. The results of the individual data are displayed in Figure 4. Neither did there appear to be any clear groups of subjects according to the categorisation functions of individuals. These results are in disagreement with those of Aaltonen et al. (1997). The lack of invariance in the present results in comparison to those of Aaltonen et al. is most likely explained by the difference between the type of stimuli employed in the two studies. Vowels which were used as stimuli in Aaltonen et al.'s study are by nature perceived less categorically than stop consonants (Healy & Repp 1982).

The responses suggest, however, that there are some differences between subjects but these can be considered to have a minor effect on the categoisation function as a whole. This is, however, a typical feature in psychoacoustical experiments such as this. In fact there is no such thing as perfect categorical function (Studdert-Kennedy et al. 1970). One explanation for some of the deviations from the general trend is that in tasks like these which are relatively long in duration the listener's task is demanding on the attentional level. In fact, a majority of the subjects told after the testing that their heads and ears were numb and they felt that they could not hear the differences between the stimuli after awhile and thus became unsure in their identifications. Apart from the attentional load, there are other factors which could explain the less than perfect categorical functions of the subjects, such as the change in the decision criteria and factors concerning the listening strategies of the subjects during the testing.

The results may also be interpreted as suggesting that there were not significant differences in the categorisation function of the stimuli continuum employed here between speakers of different dialects. The dialects of the subjects were not studied but the fact that the subjects originated from various parts of Finland indicated that the dialectical backgrounds of the subjects were heterogeneous. Therefore, it is interesting that the categorical function when represented graphically was relatively steep suggesting a sharp distinction between short and long quantities in this context. It could be that the stimuli were simple in terms of the sound structure and therefore the word medial consonant had an emphasised position which the listeners focused on in making their judgments on the identity of the stimuli. Also the fact that the stimuli consisted of pseudowords meant that the subjects relied solely on the acoustical information rather than lexical representation of the words.

In conclusion, it appears that the continuum was categorised similarly between the subjects and that the durational changes in the word medial consonant did not affect the categorisation of the adjacent sounds in general.

2.5 Experiment 2

The results of Experiment 1 provide evidence that native speakers of Finnish are capable of discriminating durational differences that cross the phonemic boundary between long and short quantity. Thus, the way in which the stop consonant was identified clearly demonstrates that it is perceived categorically along the durational continuum. The results support the assertion that variable duration of the stop closure affected only the catagorisation of the segment itself, and the categorisation of the adjacent sounds was not affected by this change in the word medial consonant duration. This is an interesting finding in light of the findings of earlier studies (Lehtonen 1970) according to which the speech of Finnish speakers demonstrates that there are in certain contexts some reciprocal relationships within the durations of adjacent sound segments which affect the quantity categorisation of these segments, as was mentioned earlier in the introduction of this chapter. Although the majority of the responses did not indicate durational influences on the categorisation of adjacent segments there were two individuals whose responses reflected this possibility. Therefore, to gain more evidence on this aspect of quantity categorisation the second experiment was conducted.

2.5.1 Research questions

In an effort to provide stronger evidence on how durational changes of a word medial stop are identified in terms of phonemic quantity, a second experiment was conducted employing a continuum which was constructed from the VCCV structure rather than from the VCV structure used in Experiment 1. Thus, in Experiment 2 the affect of the durational changes of the word medial stop was studied with a continuum constructed from the pseudoword *atta* by shortening the duration of the stop closure. The research questions concerning Experiment 2 are the following:

1. Does manipulation of closure duration affect identification and categorisation of surrounding sounds when the stimulus continuum is constructed from the VCCV structure pseudoword *atta*?

2. What is the location of the category boundary between long and short quantities in this durational continuum?

3. Is the category boundary in a different location when the stimuli continuum is constructed from the VCCV structure when compared to when it is constructed from the CVC structure?

4. What is the bandwidth of the category boundary in this durational continuum?

5. Is the bandwidth different here in comparison to that of Experiment 1?

6. Are there individual differences in the location of the category boundary and the bandwidth?

2.5.2 Method

2.5.2.1 Subjects

Twenty-one undergraduate students from the University of Jyväskylä participated in Experiment 2. They were between 21 and 30 (x = 24) years of age. Twelve of the subjects were females and nine were males. They were all native speakers of Finnish and declared to have no language, speech or hearing impairment. As in Experiment 1 all the subjects were naive as to the experimental variable being manipulated and as to the goal of the experiment. The geographical dialectical background of the subjects was heterogeneous: 29 percent of the subjects originated from the region of the Central Finland (6), 24 percent from Ostrobothnia (5), 19 percent from Häme (4), 14 percent from Savo (3), 10 percent Uusimaa (2), and 4 percent from South-West Finland (1). All of these students had participated also in Experiment 1, and the dialectical background of the subjects between Experiment 2 and Experiment 1 was similar. The lapse of time between the conduction of Experiment 1 and that of Experiment 2 was approximately 16 days (ranging from 7 days to 25 days).

2.5.2.2 Listening material, instrumentation and procedure

The stimuli employed in Experiment 2 were constructed according the same main principles as those in Experiment 1. The same Finnish speaking female who produced the original stimulus for Experiment 1 recorded the pseudoword *atta* in exactly the same way as she did in the first experiment.

A set of ten stimuli were constructed from the original *atta* word (see Fig. 6). The whole set of stimuli formed an artificial continuum in which the duration of a stop closure was varied in stepwise fashion. This time, the continuum was constructed by deleting 20 milliseconds of silence at a time from the middle of the silent occlusion of the pseudoword *atta*. The durations of the sounds were the following: the duration of the first vowel was 84 milliseconds, the occlusion of the word medial stop was 260 milliseconds and the following vowel was 103 milliseconds. The total duration of the original word was 447 milliseconds, and that of the whole set of stimuli varied from 267 to 447 milliseconds. The segmentation conventions for the phonetic durations were the same as in Experiment 1 (see pages 33-34). The Figure 5 illustrates the stimuli continuum with the different durations of occlusions. Further, the instrumentation and the procedure used in Experiment 2 were identical to that described in Experiment 1.

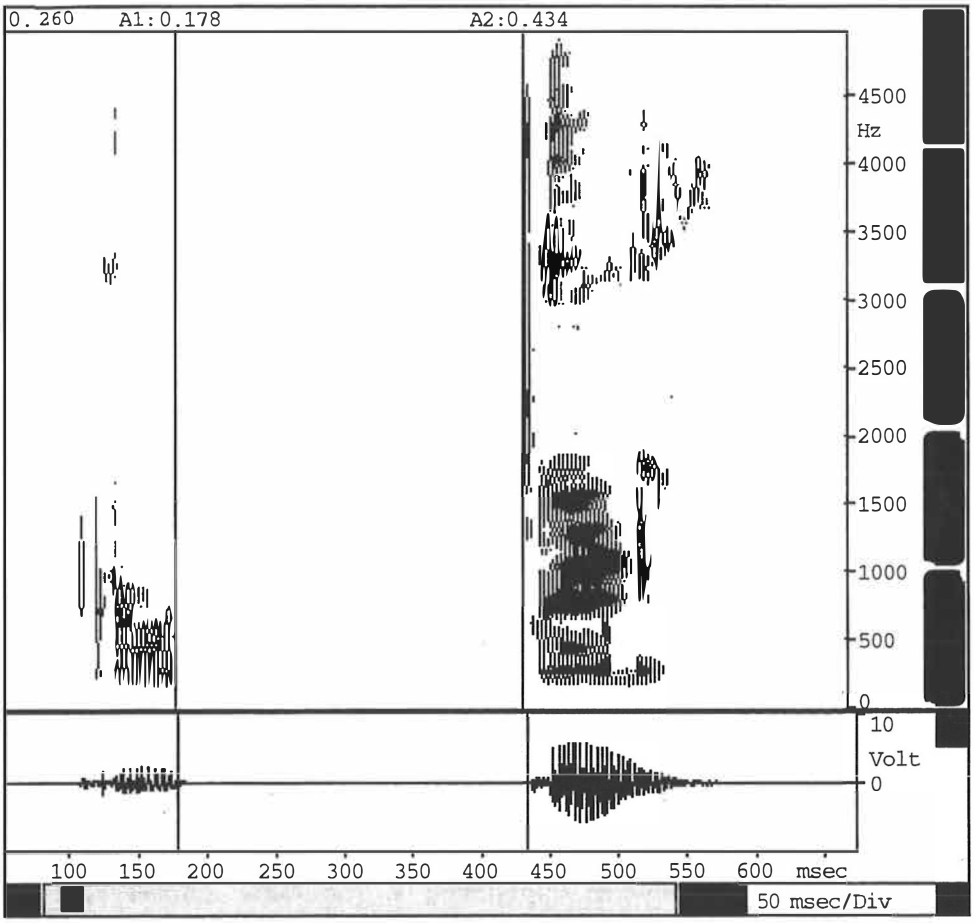

FIGURE 5 Waveform and spectrogram representation of the naturally produced pseudoword *atta* illustrating the segmentation conventions employed in Experiment 2. The graphical illustration shows that the word final vowel was emphasised. This emphatic stress at the second syllable of *atta* is similar to that in the original pseudoword *ata* in Experiment 1 (see Fig. 2).

stimuli	*ata* 1	*ata* 2	*ata* 3	*ata* 4	*ata* 5	*ata* 6	*ata* 7	*ata* 8	*ata* 9	*ata* 10
occlusion in msec	80	100	120	140	160	180	200	220	240	260

FIGURE 6 The stimuli continuum employed in the perception test of Experiment 2. Duration of the silent closure stage of the word medial dental stop was reduced in stepwise fashion by increments of 20 msec. Natural speech sounds were used as stimuli. The original stimulus was taken from the speech of a female producing the pseudoword *atta*, which is stimulus 10 in the continuum. Altogether 10 stimuli were constructed ranging in total duration from 267 to 447 msec, and the impression of the perceived stimulus shifted from *atta* to *ata*.

2.5.3 Results and discussion

All the stimuli were identified by all the subjects making 2100 identifications altogether. As in Experiment 1, the results indicate that the stimuli were identified in principle in the same way across the subjects. The following identifications were made: 97 percent (2039) of the stimuli were identified as either *ata* or *atta*, approximately 1,5 percent of the stimuli were *attaa* (32) identifications and another 1,5 percent were *ataa* identifications (29). These responses reveal that there was no ambiguity as to the quality of the sounds in this experiment.

The graphic representations of the responses in Fig. 7 demonstrate that the stimuli continuum was perceived categorically. The location of the category boundary of the stop was at approximately 125 msec. This crossover point was at a shorter duration than it was in Experiment 1. Obviously, differences in speech rate may have affected the differences in the category boundaries between the two experiments but since there was an attempt to control speech rate in the construction of the stimuli (the original stimuli were spoken within the same linguistic context by the same speaker) the rate of speech is not believed to have a significant effect on the results.

At the crossover point the proportional durations of the segments were the following: the proportional duration of the word initial vowel comprised 27 percent of the whole word, that of the word medial consonant 40 percent and that of the word final vowel 33 percent. In Experiment 1 the corresponding figures at the theoretical category boundary were the following: the proportional duration of the word initial vowel comprised approximately 21 percent of the whole word, that of the word medial consonant approximately 41 percent and that of the word final vowel approximately 39 percent of the whole word duration. These results suggest that when the proportional duration of the word medial consonant is 40 percent or more then it is categorised as long. In fact, the same tendency can be seen in Lehtonen's data (1970, 176) as well. When the proportional duration of the consonant in the original word *mätä* was increased and reached over 40 percent of the total duration of the word (42 percent and 45 percent) then the word medial consonant was categorised as long.

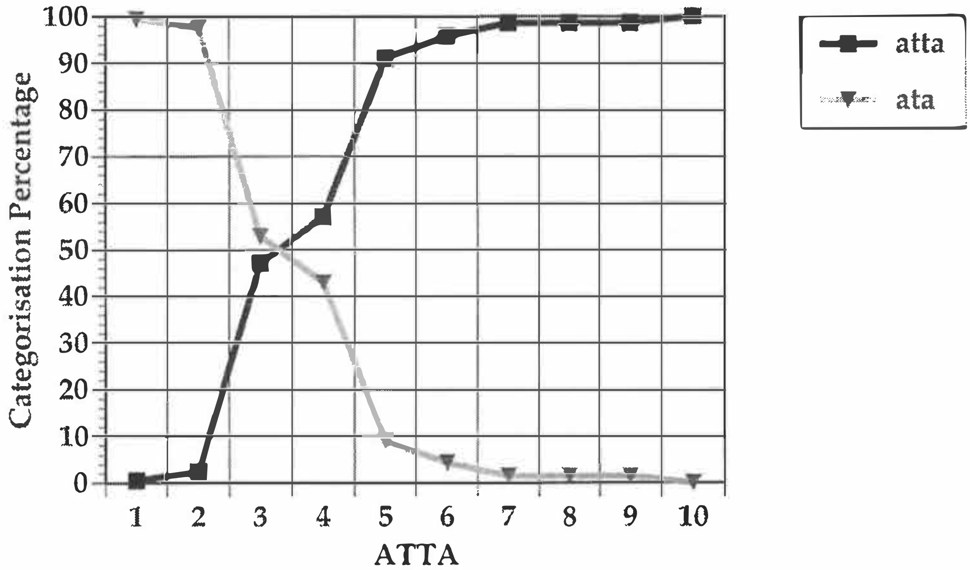

FIGURE 7 Categorisation function for the *atta* continuum. The 10 stimulus items are shown on the abscissa. The stimulus number 10 is the original stimulus from which the rest of the stimuli were constructed by shortening the occlusion of the stop by 20 msec at each step of the continuum. The category boundary is located near stimulus *atta 3*.

Furthermore, the results could be interpreted as showing a reciprocal relationship between the proportional durations of the word medial consonant and that of the word final vowel. In both of the experiments it appears that when the proportional durations of the word medial consonants became larger than those of the word final vowels then the word medial consonant was categorised as a long consonant. In Experiment 2 the proportional durations of the C and V2 were 40 and 34 percent respectively at the crossover point, but when the same figures were of the order of 35 and 36 percent in the stimulus *atta2* then the word medial consonant was categorised as short. In Experiment 1 the figures in question were 41 and 39 percent at the crossover point but the stimulus *ata2* with the figures 36 and 42 percent was categorised as a VCV word rather than a VCCV word. Therefore, it seems that both the proportional size of the word medial consonant and the relationship between it and that of the word final vowel affect the way in which the quantity of the word medial consonant in the VCV structures is categorised. Thus, the actual absolute duration of the sounds does not seem to have a decisive role in the location of the category boundary between short and long quantity degrees. Furthermore, when the results of Experiment 1 and 2 are compared the assumption (e.g., Lehtonen 1970, 174) is confirmed according to which the longer the word final vowel is the longer the preceding single consonant can be before it is categorised as long.

The syntagmatic relationship between the word initial vowel and word final vowel does not seem to have any decisive role in the quantity categorisation of the word medial consonant. Since the physical durations of the vowels were not altered between the different stimuli, neither did the relation between the durational proportions substantially change between the word initial and word final vowels.

The bandwidth of the identification was approximately 57 msec. This is virtually the same as that in Experiment 1 (58 msec). However, the shape of the curves or the steepness of the category boundary between the two experiments appear to be different: the category boundary in Experiment 2 appears to be less steep than that in Experiment 1. But since there was no difference in the bandwidth it cannot be said that the shape of the identification curves indicates that the stimuli employed in Experiment 1 were categorised more distinctly than those in Experiment 2. In this connection it should be noted, however, that the order of the experiments may have had an effect on the categorisation functions. When Experiment 2 was conducted the subjects were already familiar with this type of psychoacoustical experiment and with stimuli similar to those used in this experiment, and the listening strategies and expectations could have been different in the two experiments.

The identification responses of the individual subjects are presented in Figure 8. These responses revealed that the deviant responses as to the quantity category of the word final vowel, i.e., *ataa* and *attaa* responses, were traceable to the same individuals as in Experiment 1. The male subject (Subject number 6 in Fig. 8) made the most deviant identifications: he identified the stimuli from the shorter end of the duration continuum in 28 of the cases as *ataa*, and in 20 cases in the stimuli from the longer end of the continuum as *attaa*. The *ataa* identifications were distributed in his responses in the following way: 10 times in response to stimulus 1, 9 times to stimulus 2, 7 times to stimulus 3 and twice to stimulus 4. The *attaa* identifications were distributed in the following way: 5 times in response to stimulus 5, 3 times to stimuli 6, 2 times to stimulus 7 and 8, and once to stimulus 9.

The female subject identified the shorter end of the continuum stimuli as *ataa* twice when stimulus 2 was presented and once when stimulus 3 was presented. The *attaa* identifications she gave in the following cases: 5 times when the stimuli 5 and 6 were presented, 3 times in response to stimulus 7, twice to stimulus 8 and once to stimulus 9. It appears that these two individuals seem to identify the stimuli in a deviant way to the rest of the subjects in both of the experiments. Thus, it seems that the way in which the stimuli continua were constructed did not affect to a significant extent the way in which the quantity category of the word final vowel was identified by these two individuals nor the rest of the subjects. It could be that the adopted response strategies or the idiolects of these two speakers affected the way in which they responded in the two experiments.

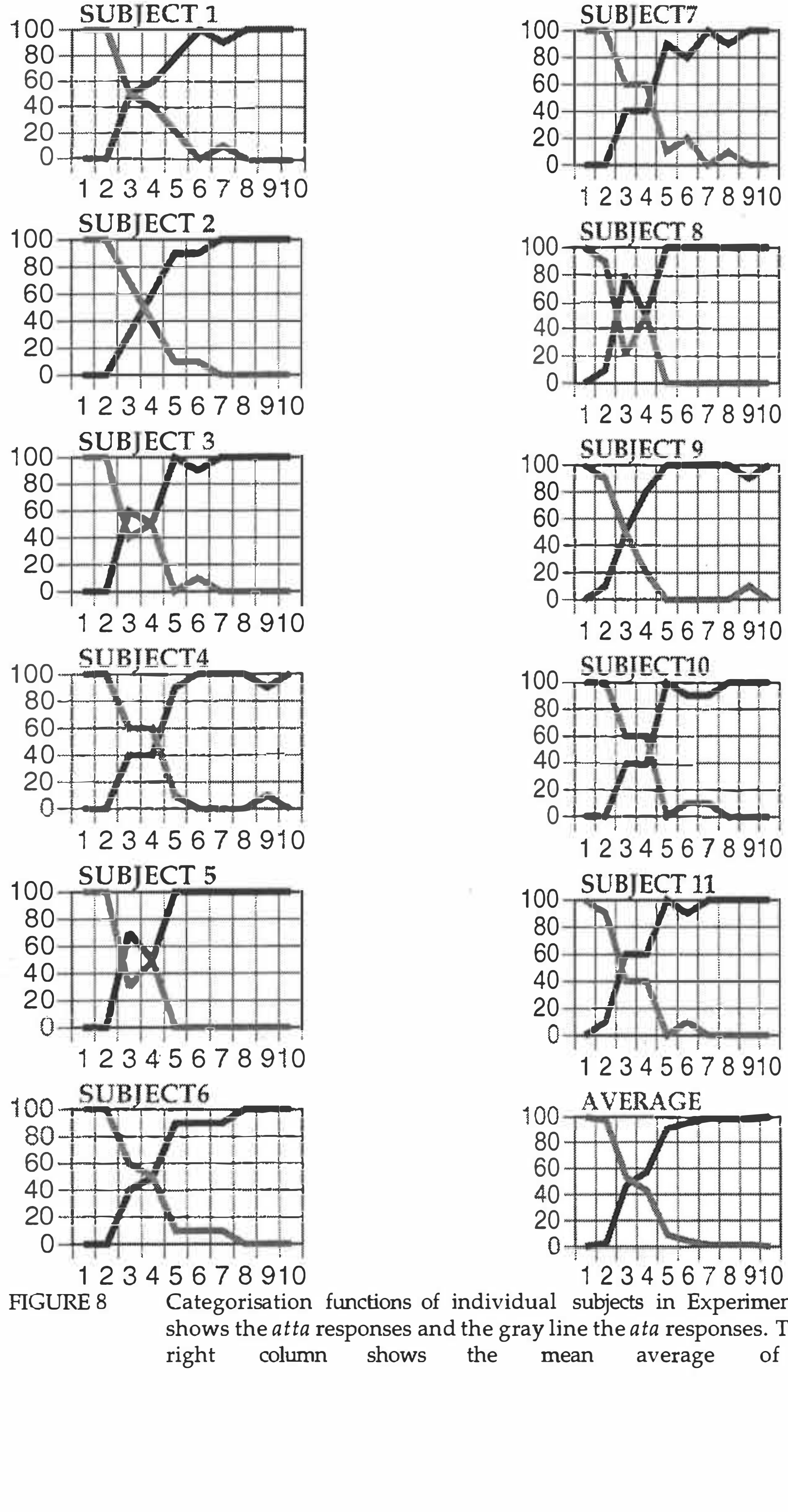

FIGURE 8 Categorisation functions of individual subjects in Experiment 2. The black line shows the *atta* responses and the gray line the *ata* responses. The last graph in the right column shows the mean average of the responses.

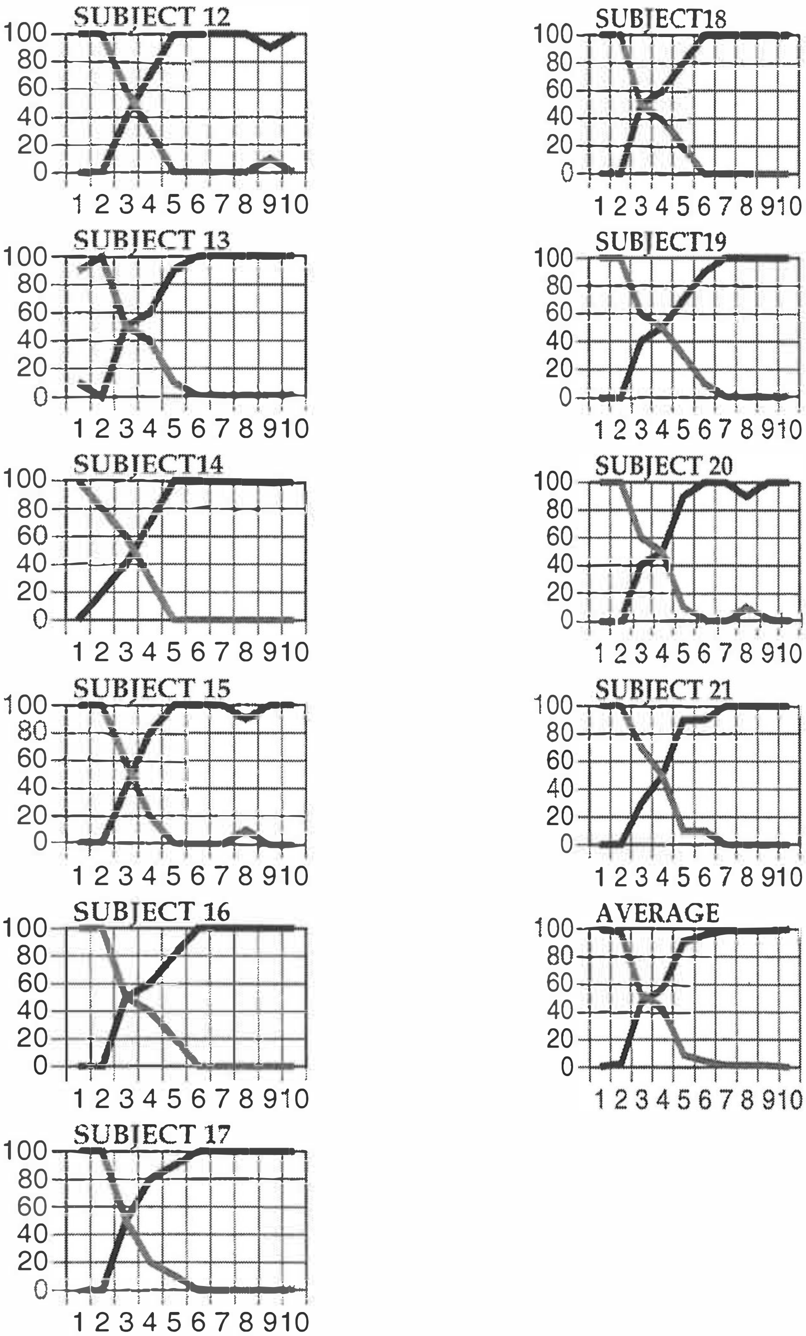

FIGURE 8 Continues

The result that in general the quantity categories of the adjacent sounds were not affected by the changes in the duration of the word medial consonant differs from the results of Lehtonen. In his study (1970, 184) the stimuli, in which the original long word medial consonant was shortened, were relatively systematically identified as having also a long word final vowel (*mättää*). No explanation for this discrepancy between the results of Lehtonen and the present study is readily available apart from the obvious fact that the stimuli were different. One explanation, however, could be the fact that he used real Finnish words as the original stimuli which also had real word counterparts (e.g., *mätä* 'rotten' and *mättää* 'to shove'), whereas in the present study the stimuli were not meaningful in Finnish. Therefore, the perceptual analysis of the stimuli in the present study had to rely more on the acoustics of the stimuli presented. In employing real words the knowledge of the possible alternatives of real Finnish words between the temporal changes of the segments in the stimuli continuum may have facilitated the variability in the responses in Lehtonen's study.

The graphical presentation of the individual categorisation functions is presented in Fig. 8. These results indicate that most of the subjects located the categorical crossover point in between stimuli 2 and 3. As in Experiment 1, there does not seem to be any drastic difference in this function between the individuals. It should be noted, however, that the categorisation function between categories is not as steep as it was in the responses in Experiment 1. Perhaps the durational and proportional durations of the stimuli continuum were not as distinct as those in Experiment 1, and thus the stimuli were not as good exemplars of the word structures in questions as those in Experiment 1.

The categorical functions of the individual subjects as well as all the categorical functions of the two experiments presented in this Chapter demonstrate that there are no absolute durations for short and long quantity degrees of the consonants in VCV/VCCV structures. Nevertheless, the variable locations of the category boundary were still located within a relatively restricted durational stretch. It appears that some factor or factors affect/s within which the crossover point of durational categories fall. In a study by Nakajima, ten Hoopen, Hilkhuysen & Sasaki (1992) in which nonspeech sounds with similar stimuli durations to the present study were employed the point at which the listeners changed their categorical judgement from short to long was around the same as in the present study (120-160 msec). This evidence in addition to other evidence may be an indication that there is some kind of natural area in the durational continuum in which our perception changes from short to long. In fact, researchers of categorical perception have suggested that category boundaries are based on natural sensitivities of the auditory system (e.g., Rosen & Howell 1987, 120-121). Thus, it is known that since there is an element of learning in categorical perception this learning may well be facilitated by some kind of natural perceptual sensitivity of the auditory system. Whether this perceptual sensitivity is the product of spoken communication of whether it is otherwise characteristic to humans or whether the same sensitivity is encountered in other species are questions which should be answered in the future in order to understand more about temporal speech processing in general.

Also the fact that there seems to be a larger durational area in which the long quantity degree is located in comparison to the area of short quantity degree is evident from the results of the two experiments. The same tendency is also clearly evident in previous research on durational aspects of quantity distinction (e.g., Lehiste 1970, Lehtonen 1970, Magga 1984, Engstand & Krull 1994a, 1994b). Penttilä (1963, 21) noted that in Finnish short sounds cannot be lengthened significantly without them becoming long whereas the durations of long sounds can be considerably extended without any inconvenience. Trubetskoy (cited in Lehiste 1970, 36[1]) also suggested already in the 1930s that the short degree quantity degree seems to be restricted to a narrow point in time whereas the long degree has more of a length dimension which is stretchable at will. This suggestion gained more experimental support in the experiment described here.

2.6. Conclusion

The two psychoacoustical experiments described in this chapter gave indications that artificial changes in sound durations in the Finnish context affect only categorisation of that particular segment. The fact that the stimuli were not meaningful words in the language of the subjects has to be remembered in interpreting the results. In previous research (Lehtonen 1970) in which real words were employed there were some signs that the duration affects the categorisation of the adjacent segments in the cases in which the different categorisations resulted in existing Finnish words. Perhaps when an acoustical signal is ambiguous listeners have to pay more attention than normally to certain prominent acoustical characteristics in order to judge the phonemic function of the signal.

The results indicated that the adjacent sound durations affect the categorisation of the consonants in VCV/VCCV structures: the duration of the consonant has to be longer than that of the word final vowel in order for the consonant to be categorised as long. This tendency was evident in both of the experiments. This means that the acoustic characteristics by which words can be distinguished from each other, are not necessarily limited only to that acoustic segment which mainly represents the distinctive segment on the word structure level. In other words, the quantity distinction can be based on the contrast between successive

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1 Trubetskoy, N.S. 1936. Die phonologischen Grundlagen der sogenannten 'Quantität' in den verschiendened Sprachen. Scritti in onore di Alfredo Trombetti (Milano), 155-174.
Trubetskoy, N.S. 1938. Quantität als phonologisches Problem. Actes du IVème Congrès International de Linguistes (Copenhague), 117-121.

segments. It should be noted, however, that the durations of all the adjacent sounds do not affect the categorisation to the same extent. In VCV/VCCV structures only the consonant and the word final vowel played decisive roles in the quantity categorisation of the word medial consonant.

The two experiments clearly demonstrated that there is no absolute duration for short and long quantity degrees in VCV and VCCV structures. Rather the categorical boundaries are flexible. On the quantity categorisation level the duration of the word final vowel alone does not have a decisive role in the quantity category of the word medial consonant. The durational relationship of the word medial consonant and the word final vowel on the other hand occupies a key position in determining the quantity degree of the word medial consonant. Whether this relationship and the category boundaries in the artificial durational continua employed here are based on some kind of natural perceptual sensitivity or whether they are learned are interesting questions for the future.

Somewhat surprisingly, the results showed that the dialectical background of the listeners did not affect the categorisation of the word structures employed here. It would be interesting to investigate whether the language background of the listeners would affect the categorisation of the continua employed here. Since there is an element of learning as well as natural tendencies in categorisations it could be expected that there would be a difference between speakers of different languages in this task. Necessary information on the temporal processing involved in quantity categorisations would also be gained from carefully designed studies on infants and on animals. The auditory temporal processing of young infants will be investigated here in the next chapter.

3 CATEGORISATION ACCORDING TO SOUND DURATION IN DYSLEXIA: PERCEPTION

3.1 Purpose

The purpose of this chapter is to investigate the ability of young infants with high genetic risk for dyslexia as well as their Finnish speaking dyslexic parents to perceptually categorise speech sounds with varying duration. Two auditory perception experiments were conducted, one involving adult subjects and another with 6 month old infant subjects (using duration as the research parameter). The experiment involving adult subjects is presented first since apart from being an interesting topic to study as such it forms a reference point for the study on infants. A variety of auditory perceptual deficiencies in dyslexics have been suggested in the past (e.g., Orton 1937, Bakker 1967, Zurif & Carson 1970, Bakker 1971, Boder 1973, Tallal 1980, Brady, Shankweiler & Mann 1983, Godfrey, Syrdal-Lasky, Millay & Knox 1981, Werker & Tees 1987, Farmer & Klein 1995). In the last twenty years or so one of the most contested hypothesis on the perceptual deficiencies in dyslexia suggests that poor processing of the rapid temporal features of stimuli may well be one of the underlying factors behind the condition. This suggestion is due to the influential works of Tallal and her colleagues on language impaired and reading impaired children. Although Tallal and other researchers have found indications of differences in certain temporal aspects of perception between dyslexics and controls, surprisingly few studies have investigated the durational aspect of perception. The current study by focusing on the durational aspect of perception, elucidates by experimental evidence the abilities of dyslexics and infants with high genetic risk for dyslexia to perceive the durational features of speech. Firstly, an overview of the existing knowledge is provided by reviewing the studies concerned specifically with duration in one form or another: the studies concerned with durational changes within stimuli, which are considered most relevant to the current study, are reviewed first, after which the studies involving duration in terms of interstimulus intervals are reviewed. The details of the studies reviewed are also summarized in Table 1 and 2 (pages 62-64 and 74-81). Furthermore, some aspects of the tasks, the stimuli and the selection of the subjects in some previous studies and their influence on the outcome of the experiments, are focused on briefly before providing reports on the two experiments of this chapter.

3.2 Duration and other temporal features in the studies of dyslexia

3.2.1 Durational variations with verbal and nonverbal stimuli

One of the rare studies which specifically addresses the question of categorisation by the duration of sounds is the doctoral dissertation of Pallay (1986). For several experiments Pallay constructed stimuli continua which were based on durational differences of speech sounds. The following three durational continua were utilised: a /ba/-/wa/ -continuum in which the manner of production changed according to differences in the duration of the first formant transition, a /da/-/ta/ -continuum in which the voicing of the sound was affected by differences in the duration of voice onset time, and a nonverbal continuum which was constructed from the /ba/-/wa/ continuum by including only the first formant transition of the stops which varied in duration (thus instead of speech sounds the stimuli sounded like bleeps). Seven to nine year old poor readers and their matched controls served as subjects. Two types of tasks were administered, a forced-choice identification task and a discrimination task. Pallay's results on identification tasks (using all three continua) indicate that both the subject groups categorise sounds similarly and no group difference was found. The discrimination tasks with speech stimuli revealed differences in the performance of the two subject groups: dyslexic children were less consistent in catogorising sounds according to subtle changes in duration. It is noteworthy that a contributing factor in the group difference was the reduced performance of only four individuals out of eight (Pallay 1986, 59). It should also be noted that in the nonspeech discrimination task this difference did not emerge. In fact both the subject groups performed considerably worse in the discrimination task with nonspeech stimuli than in that of the speech stimuli. Interestingly, though, the dyslexics showed more consistency in labelling the short duration format transition stimuli as short than they did in labelling the long duration formant transition stimuli as long (Pallay 1986, 63). Since the group difference was evident in tasks involving speech stimuli but not in those of nonspeech stimuli, Pallay concluded that her results cannot be viewed as conclusive in showing that dyslexics have a deficiency in processing brief temporal information in general. The nature of the nonspeech stimuli, however, as Pallay (1986, 72) herself noted, makes it difficult to rule out the possibility that the listeners might have perceived the intensity difference rather than or in addition to the temporal differences. In any event, the results seem to provide evidence on dyslexics' difficulties in processing subtle differences of phonetic information with varying duration. It is important to note that the criteria for inclusion in the dyslexia group in Pallay's study was that the subjects were diagnosed[1] as being at least five months behind their chronological age peers in reading performance. It is a more common practice that subjects in dyslexia groups are at least a year and often even two years inferior in reading skills to their peers. Therefore, the fact that these subjects were not necessarily severely dyslexic should be borne in mind before drawing any far reaching conclusions on the basis of these results.

The investigation of Steffens, Eilers, Gross-Glenn and Jallad (1992) found clear group differences between dyslexic adults and their matched controls in terms of temporal auditory processing. The stimuli in their study was constructed to measure linguistic categorisation by the duration of a silent interval. A 11 step continuum was constructed from the syllable /sta/ by decreasing 13 msec of silence at each step between the sibilant and the vowel, rendering eventually the perception of /sa/. Carefully selected adult dyslexics[2] and their matched controls served as subjects. The study employed a forced-choice categorisation task (/sa/ or /sta/) as well as two discrimination tasks, one with an ABX paradigm (match the third stimulus with A or B) and the other with a Same-Different (SD) paradigm. The stimuli in the discrimination tasks were arranged in pairs which were separated by three

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1 The level of reading was measured by the Woodcock Reading Mastery-Word Attack and Word Recognition subtests (Woodcock & Johnson 1977). The normal subjects were at or above grade level in reading. The IQ level (measured by the Raven Coloured Progressive Matrices) was at the 85th percentile for the dyslexics and at the 89th percentile for the controls. All the subjects had normal hearing as measured by a standard audiometric battery.

2 The members of the dyslexic group were checked for a history of suggestive familial dyslexia. Intelligence level (IQ 90 or higher) was assessed with the Wechsler Adult Intelligence Scale-Revised WAIS-R. The spelling and reading skills were assessed with Gray Oral Reading Test Revised, GORT, Letter-Word Identification Subtest of the Woodcock-Johnson Psycho-Educational Battery WJL, reading comprehension with Passage Comprehension Subtest of the Woodcock-Johnson Psycho-Educational Battery WJP, decoding with Word-Attack Scale Subtest of the Woodcock-Johnson Psycho-Educational Battery WJW, and Nonsense Passage Errors (NPE) and Nonsense Passage Time NPT, and spelling with Wide Range Achievement Test-Revised/Spelling WRAT-R. Normal readers were individuals with no history of reading or academic difficulties. All subjects received vision and hearing screenings. All individuals were monolingual native speakers of American English.

continuum steps. The results on the categorisation task show that dyslexics require greater silence duration than normal readers in order to shift their perception from /sa/ to /sta/: the boundary between the two syllables occurred at approximately 20 msec in the judgments of the control subjects whereas it was clearly above 20 msec for the dyslexic subjects. In the discrimination tasks the performances of the two subject groups did not differ significantly. The only statistical difference in group *d'* scores[1] emerged from the discrimination of the stimulus pair 2 and 5 (duration of the silent interval was 117 msec and 78 msec, respectively): the dyslexics failed to discriminate the pair 2-5 above chance whereas the controls discriminated this as well as all the other stimuli pairs above chance. This finding does not seem to be substantial, since according to the original categorical perception hypothesis stimuli within a category (as was the case in the stimulus pair 2 and 5) are not well discriminable. In fact, if anything the dyslexic adults seemed to be more normal in their judgments than the controls in this respect. The fact that the stimuli in the discrimination tasks were always separated with an equal size continuum step might have effected the results. The stimuli which are highly discriminable are usually between categories the discrimination of which was not tested in this procedure. An interesting finding as noted by Steffens et al. themselves (1992, 198) is that the performance of individual subjects was heterogeneous in this study as well as in the majority of the studies involving dyslexics. In general, the standard deviations were greater for the dyslexics than for the controls, and the dyslexic males tended to deviate more from the controls than did the dyslexic females (Steffens et al. 1992, 198-9). Steffens et al. (1992) conclude that these data offer evidence on deviations in the temporal domain of some dyslexics. Again in weighing the importance of this evidence, attention should be paid to the selection of the subjects. Steffens et al. (1992, 199) note that the dyslexic subjects in this study might have been so called compensated dyslexics. The dyslexics ability to read although being significantly poorer than that of the controls was measured to be above the standard (the mean score was 107.72 and the standard is 100). They had, however, severe difficulties in processing nonsense syllables. It seems that the perceptual deficit these dyslexics might have had was manifested in situations in which there existed no contextual information to facilitate phonetic identification (Steffens et al. 1992, 199).

Watson (1992) also examined the auditory temporal processing skills of dyslexic adults and controls[2]. A discrimination task in which varying

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1 The group *d'*score which Steffens et al. computed for all the three continua is based on a signal detection model created by Green and Swets (1966). The *d'*score includes response bias in the statistical analysis by calculating the probability of a correct response with respect to the rate of false responses (Steffens et al. 1992, 198).

2 All the subjects had normal hearing (passed bilateral pure-tone audiometric screenings), vision (according to the subjects' own reports), had at least 90 IQ on the Wechsler Adult Intelligence Scale Revised and had no emotional disturbances, social disadvantages, or lack of educational opportunities (according to social and educational histories). The subjects in dyslexia group had a difference to normal population of one standard deviation or more between predicted and obtained mean reading score on three Woodcock-Johnson reading subtests. (Letter-Word

durations of stimuli were employed was administrated with tones as stimuli, the standard stimulus being 100 msec in duration and the other durations ranging from 108 to 256 in milliseconds. Univariate analyses of variance yielded a significant difference between the performances of the two subject groups (Watson 1992, 152). The mean percent of correct responses of the dyslexic group was significantly lower than that for the control group on the least-significant difference test: the dyslexics responded correctly in approximately 77 percent of the cases whereas the controls responded correctly in approximately 84 percent of the cases. Unfortunately, it is not apparent in Watson's article in which specific cases of stimuli did the differences between the subject groups emerge. Therefore, Watson's account of her study does not provide evidence on the dyslexics and controls performances in detecting differences of specific durations. Watson (1992, 153) interpreted her findings as suggesting some kind of relationship between reading difficulties and deficient temporal processing abilities. Furthermore, she suggested that this deficiency may contribute to dyslexics who specifically have poor phonics abilities. She drew this conclusion from the fact that the dyslexics in her study had problems with phonics[1] rather than in language comprehension or in oral language[2]. Once again, in this study as in the other two studies, the data showed that the deficiencies detected in dyslexics were restricted only to some of the subjects. The majority of the dyslexics performed as well as the controls in the temporal processing tasks. Watson (1992, 154) was of the opinion that a deficiency in temporal processing is unlikely to be the sole cause of dyslexia, if there exists a causal relationship at all, but it may be responsible for the disorder together with other deficiencies.

In another study, Watson and Miller (1993) examined among other things the discrimination of duration in various tasks. Among the measures employed in their study where those which tested if there was a difference in the ability to discriminate nonverbal and verbal stimuli with various durations in dyslexic[3] and nondyslexic adults. The following two tasks were administered involving duration of sounds: discrimination of pure tones with varying durations and detection of extra tone with varying durations among nine tones. It should be noticed that the latter discrimination task, the embedded tones task, demanded more than detection of durational differences

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Identification, Word-Attack and Passage Comprehension). The subjects in the normal reading group were otherwise matched to the dyslexic subjects except that the controls had a mean standard score of 95 or higher on the three reading subtests of Woodcock-Johnson.

1 The term *phonics* means the rules concerning grapheme to sound correspondence. In Watson study the dyslexic subjects had difficulties reading nonsense words, and phonics skills are needed in order to successfully read words with no meaning.

2 It should be noted that oral language abilities were not formally tested in these subjects.

3 The dyslexic subjects were tested for IQ level (90 or higher with WAIS-R) and their reading level was measured with three reading subtests of Woodcock-Johnson Psychoeducational Battery. Reading score was one standard deviation or more below the predicted score. The control subjects' IQ levels were measured by the Culture Free Intelligence Test. All the subjects were tested for normal hearing with pure-tone threshold audiometric screenings (Watson & Miller 1993, 853).

since it also measured auditory attention (Watson 1987) and perception of rhythm. The performance of the dyslexics did not differ statistically from the controls in either of these tasks. Watson and Miller also studied the discrimination of verbal stimuli with the same subjects in a task in which the listeners was required to discriminate between /ta/ and /ka/ when the test syllables were proceeded and followed by the syllables /fa/ and /pa/. The performance of the two subject groups was significantly different in this task. Although Watson and Miller (1993, 854) report that the duration of the syllables varied between 75 and 250 msec it is not apparent if the duration of the stimuli affected these results. Thus, the results of this study provide no evidence on the perception of duration in speech stimuli. However, this study indicated that there is no difference in the perception of duration in nonspeech sounds between adult dyslexic and control subjects. Interestingly, this finding disagrees with Watson's earlier study which utilised exactly the same stimuli and procedure[1]. Perhaps the subject sample of this latter study lacked those dyslexic subjects who may have difficulties with perceptual temporal processing, keeping in mind that in the 1992 study Watson noted that only some of the dyslexics were deviant in this respect.

Brandt and Rosen (1980) studied among other things children's ability to categorise synthetic syllables which varied in voice-onset time. Both discrimination and identification tasks were administered to dyslexic and control children[2]. The results show that all the dyslexic children categorised the stimuli similarly: the phoneme boundary was at 37.33 msec, shorter durations were consistently labeled as /d/ and longer as /t/ (Brandt & Rosen 1980, 329-330). The phoneme boundary for the control children was at the shorter duration of VOT, 35.02 msec (Brandt & Rosen 1980, 331). Brandt and Rosen (1980, 335) conclude that the major finding of their study was that dyslexic children were not significantly deviant in their ability to categorise speech syllables. Unfortunately, they failed to compare the group performances directly by statistical means. If statistical comparisons were made, it seems likely judging from the plotted curves that there may well have been group differences in this study. Brandt and Rosen noticed, however, that dyslexic children's discrimination between phoneme categories was poorer than expected on the basis of the results of the identification task whereas that of control children was the same as expected. They interpreted this finding as showing that the dyslexic children may have been at an earlier developmental

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1 However, in the more demanding pulse-train discrimination task and the extra tone detection task the results did not differ significantly between the subject groups of the two studies by Watson.

2 The dyslexics were all at least 2 years behind children with the same chronological age in reading level as determined by the Gray Oral Reading Test and The Slosson Oral Reading Test. None of the children displayed any obvious neurological or behavioral problems. The parents of the control group children reported that their children were at least grade level in reading ability and did not display any learning or behavioral problems. All the subjects were tested for normal audiometric thresholds.

stage than their age-matched control children (Brandt & Rosen 1980, 336). They adopted the developmental view on the basis of the earlier findings of Wolf (1973) in which similar tendencies to those found in the dyslexics here were found in younger children, but normal adults have been reported to discriminate even better at the phoneme boundary than predicted on the basis of identification (Liberman, Harris, Kinney & Lane 1961). This interpretation of theirs means that older speakers may be able to perceive and utilise subtle differences in acoustic information better than younger speakers, whose perception seems to be more phonemically based. Brandt and Rosen preferred the idea of developmental differences in the responses but did not dismiss the opposing idea according to which the dyslexics may in fact have been less phonemically based in their responses than controls since their results showed a flatter discrimination level between categories. Another word of warning in terms of considering the results gained from Brandt and Rosen's study: the control group was comprised of only four individuals and the dyslexia group was also relatively small including only 12 subjects in all[1]. The small number of individuals in each group has to be taken into consideration since, as has been noted earlier, there appear to be many different deficits in dyslexics and this may explain the possibility that in such a small group such differences did not emerge.

1 The twelve subjects of the dyslexic group were further divided into three equal sized groups according to performance in verbal ability measured by the Wechsler Intelligence Scale for Children.

TABLE 1 Dyslexia studies involving perception of durational variations with verbal and nonverbal stimuli.

Study	Age of subjects years; months	N + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Brandt & Rosen 1980	dyslexics 8; 4 - 12; 4 (M= 10; 5) controls 9; 3 - 12;1 (M= 10; 5)	12 dyslexics; all male 4 controls all male	identification	verbal response	synthesised 11 point continuum /da/-/ta/ (with varying VOT, -20 - +80 msec)	350	4000	no?
			AX discrimination (same-different)	the same as above	the same as above	the same as above	1000	no?
Pallay 1986	7-9 (M=8; 7)	8 dyslexics 11 controls	identification	verbal response (forced choice)	5 pairs of syllables; composed of 2 formants /ba/-/wa/	360 (duration of the transition 30-100)	3000	no
			discrimination (same-different)	the same as above	the same as above	the same as above	3000	yes
			identification	verbal response	5 pairs of syllables (varyingVOTs) da-ta	360 (VOTs 0-+70)	?	no
			discrimination (same-different)	the same as above	the same as above	the same as above	?	yes

TABLE 1 (Continues)

Study	Age of subjects years; months	N + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Steffens, Eilers, Gross-Glenn & Jallad 1992	adults dyslexic M= 39; 5; controls M=33; 3	18 dyslexics; 9 male, 9 female 18 controls; 9 male, 9 female	categorisation (forced choice) in reference to either of the endpoint stimulus	pressing buttons	synthesised 11 point continuum /sta/-/sa/ with decrease of13 msec of silence at each stimuli	300-430	500 (each stimulus was presented twice in succession with 500 msec ISI)	yes
			discrimination (same-different)		the same as above	300-430	500	no
			discrimination ABX-paradigm			300-430	500	no
Watson 1992	college students	20 dyslexics 25 controls	duration discrim-ation	?	tone (standard 1 kHz, 100 msec and variations ranging 8 to 256)	100 and 8-256		yes
Watson & Miller 1993	dyslexics or learning disabled?? M=24 controls M=22	24 dyslexics, 16 males, 8 females 55 controls, 20 males, 35 females	temporal processing (tonal duration)	?	tone 1kHz	100 (standard) 8-256 (variations)	?	no

TABLE 1 (Continues)

Study	Age of subjects years; months	N + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	
Watson & Miller 1993	dyslexics or learning disabled?? M=24 controls M=22	24 dyslexics, 16 males, 8 females 55 controls, 20 males, 35 females	temporal processing (pulse) discrimination	?	tone 1 kHz	20	40 (standard) 40-90 (variations)	no
			embedded tones	?	detecting an extra tone in a sequence of nine tones (300-3000 Hz)	10-200		no
			temporal order dis-rimination	?	tone 1 550 Hz tone 2 710 Hz	20-200		yes
			discrimin-ation (forced-choice)	?	/ta/- /ka/ preceeded and followed by /fa/ and /pa/	75-250		yes

3.2.2 Durational differences in the interstimulus interval

Duration, in the form of the interstimulus interval (ISI), had a role in the study by Hurford and Sanders (1990) in which dyslexic children's[1] ability to discriminate CV syllable pairs with varying interstimulus intervals was studied. The subjects of their study were approximately 8 and 10 years old forming two age groups for both the dyslexic children group and the control group. The stimuli were comprised of voiced stops /b, d, or g/ and the front closed vowel /i/. The durations of ISIs varied between syllable pairs from 10 msec to 400 msec (see the details of this study in Table 2 in which the details of this and the other studies reviewed here are summarised). Significant group differences were found between the performances of the youngest dyslexics and the rest of the subject groups. Although there was a difference between the performance of the older dyslexics and their age matched controls this difference did not reach a statistical significance. Thus, the data showed a tendency according to which the youngest dyslexics were poorest in the task and the older dyslexics were on the same performance level as the older control children. They also measured response latencies but those results did not indicate any significant differences between any of the subject groups. Hurford et al. (1990, 404) concluded that their results indicate a deficiency in the younger dyslexic children in the discrimination of CV syllables that begin with voiced plosives with brief phonemic information, but that their phonemic processing system may develop at a delayed pace.

Several comments on their experiment are due here. Firstly, Hurford and Sanders failed to offer any explanation for the inconsistencies of the results regarding the effect of duration of ISIs: namely, the performance was least accurate at 80 msec ISI (which was from the middle of the continuum) in all the subject groups. Secondly, the screening of the subjects did not include matching of the IQ levels of the various subject groups. This was due to the fact that the control children's IQ scores were not measured. Thirdly, although the task included same -different responses this does not mean that the task was simply a discrimination task. With the type of stimuli and the task requirements it appears that also identification or categorisation of the stimuli was demanded for a successful performance. Also the nature of the task was demanding on the memory of the subjects (had to compare two syllable pairs). Fourthly, the listening conditions were variable between the subjects and not ideal in any of the cases since the testing was conducted in a school classroom with the surrounding noise of the school, a fact which may have affected the

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1 All children had normal hearing which was assessed with an audiometric exam. Dyslexics readers with WISC-R (Wechsler 1974) full-scale IQs were above 90. The IQs of the control subjects were not assessed. Reading ability was tested either with the Woodcock-Johnson Psycho-Educational Battery (Woodcock & Johnson 1977) or with the Comprehensive Test of Basic Skills (CTBS/McGraw-Hill 1973). There was a significant difference in the reading scores with the dyslexics scoring remarkably lower in the tests. There was no significant difference between 8 and 10 year old dyslexic children in the reading scores. (Hurford & Sanders 1990, 399.)

results. Finally, the fact that the consonants in the stimuli were voiced stops did not necessarily affect the results of the dyslexics. This conclusion is based on the fact that when they used exactly the same stimuli with the longer ISIs there was no significant difference between the different subject groups. Despite some of the shortcomings of the study, Hurford et al.'s study appears to provide evidence that younger dyslexics have problems with the processing of verbal stimuli with short ISIs, and that they may overcome these problems at a later stage of development.

The study of McCroskey and Kidder (1980) involved duration as a parameter; specifically, the interstimulus interval between nonspeech tones. Their study compared the performance of dyslexic and control children[1] in an auditory fusion task. By means of the fusion task the point in time at which listeners heard two separate sounds instead of one or vice versa was determined. McCroskey and Kidder used both ascending and descending[2] stimuli sequences, and the mean of the both types of sequences was selected to be the auditory fusion point. The interstimulus intervals varied from 0 to 40 milliseconds. Pure-tone pulses were used as stimuli. The mean of the dyslexic children's responses showed that the fusion point was between 9.9 and 14.7 milliseconds and that of the control children was between 7.5 and 8.9 milliseconds (McCroskey and Kidder 1980, 21-22). This difference between groups was statistically significant[3]. The results also revealed another interesting factor: A strong age effect can be seen in the results of the control children: the fusion point became shorter with age. This finding is in accordance with McCroskey and Davis's (1976[4]) results on a study of normal children's fusion points. The same tendency was not clearly evident in the responses of the dyslexic children: whereas the oldest subjects had a shorter fusion point than the youngest children, the middle age group had even shorter fusion points than the oldest children. The standard deviations were relatively high in both the youngest and oldest age groups of reading disabled children and that could partly explain this detail concerning the results. Tentatively, one might also propose that the developmental stages in dyslexia are not as straightforward and clearly specific as in control children. Yet

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1 All subjects were tested for normal hearing and normal IQ level (according to information provided by the schools). The dyslexic subjects demonstrated reading levels that were two years below grade level.

2 In the ascending order of stimulus presentation the fusion point was defined as the longest duration of time interval between two stimuli that was still perceived as a single sound before the perception of two consecutive two-sound stimuli. The opposite was the case in the descending series in which the fusion point was defined as the first single sound response of two consecutive single-sound responses. (McCroskey & Kidder 1980, 71).

3 In their data the probability of a group difference in the responses was counted to be < .005 with a 0.5 level of confidence in the analysis of variance and covariance with repeated measures (McCroskey & Kidder 1980, 24).

4 McCroskey, R.L. & Davis, S.M. 1976. Auditory fusion: developmental trends. Scientific exhibit, National Convention American Speech and Hearing Association, Houston. This study of McCroskey and Davis was referred in to in the article of McCroskey and Kidder (1980,19-20).

another plausible explanation is that the variation among dyslexics is great in different types of tasks and this variation may partly have accounted for these results. The results of the two subject groups were consistent regarding the effect of the manner of stimuli presentation: when the stimuli sequences were presented ascendingly the auditory fusion point was higher compared to that of the corresponding descending sequences. McCroskey and Kidder (1980, 24) concluded that the results show that dyslexics required significantly longer interstimulus intervals than normal children to perceive two separate tones instead of one tone, and they interpreted this finding as providing evidence of differences in temporal processing in children with reading disorders and controls. Since nonspeech sounds were used in these experiments, it is not clear how these results are relevant to speech perception.

Tallal and Piercy (1973) included a temporal order judgment task (TOJ) [1] with a light memory load in the Repetition Test, which they introduced for the tasks used with potentially communicatively impaired children, and which was later utilised by Tallal and her colleagues in the studies on dyslexic subjects. In this version of the TOJ task, which Tallal (1980) also used in studying the auditory perceptual skills of dyslexic children[2], subjects had to indicate the order of presentation of two complex tones. The interstimulus interval varied between 8 to 428 msec. She found that dyslexic children made significantly more errors than normal children in making temporal order judgments for very brief, nonspeech tones, at short (8-305 msec) interstimulus intervals. Tallal failed to indicate the error rate at the different durations of ISI and therefore these results do not provide evidence on at which specific ISIs the difference emerged between the subject groups or if the different durations of the ISI did consistently affect the results. This study also included a discrimination test in which the stimuli were presented with varying interstimulus intervals. Tallal found that the results of this test were parallel to the TOJ task test with the shorter ISIs. Tallal (1980, 194) concluded that since the performance of the subject groups did not differ in the sequencing task with longer ISIs, this study provided evidence on the difficulties of dyslexics in perceiving rapidly presented stimuli rather than on difficulties in mere sequencing tasks. She also stated that since the performance within dyslexia

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1 Bakker (1971) and Corkin (1974) found that dyslexic children had specific difficulties with judging the order of sequences auditorily (letter sounds in the former study and digits in the latter) in TOJ tasks. In neither of these studies were the ISIs varied. The tasks employed in these studies could be regarded as having a relatively high memory load since long series of items were utilised. Therefore, the results cannot be seen as direct evidence of the deficit in temporal order perception.

2 The dyslexic children were comprised of those 1) who fitted in a formal diagnosis of specific developmental reading delay following extensive psychological, neurological and educational evaluations. Also these children had 2) normal hearing on standard audiometry, had 3) normal visual acuity on standard ophthalmologic examination, had 4) at least above average intelligence (>85 as measured by the Wechsler Intelligence Scale For Children- Revised test, 1974), did 5) not have obvious gross emotional disturbance and were 6)at least 1 year below chronological age grade in composite reading skills (measured by the Metropolitan Reading Test). The control children intelligence was tested by standardized nonverbal intelligence test. (Tallal 1980, 185-186.)

group was heterogeneous in this task (only forty-five percent of the dyslexics children's performance was worse than that of the worst control children, the rest performing similarly to the normal reading subjects) further studies are needed on the subject.

Stark joined Tallal in a later study (Tallal & Stark 1982) in which they investigated the abilities of dyslexic children to perceive rapidly presented stimuli. The same procedures and stimuli were utilised but the selection of the dyslexic children[1] was more controlled than in the previous study of Tallal's (1980). It appears that although the subjects were controlled for not having obvious language disorders other than reading related problems, it seems that the selection of the subjects varied also according to the type of dyslexia they demonstrated: in this study the subjects included those who had more problems in the comprehension of written text than in phonics skills (this was revealed by good performance in the nonsense word reading test while the test assessing comprehension significantly differentiated the two subject groups but the reverse was the case in the earlier study by Tallal (1980) in which the performance of the dyslexics was poor in the nonsense word tests. Contrary to Tallal's earlier findings, the results of the TOJ task with varying ISIs did not indicate any significant differences between dyslexics and controls (Tallal & Stark 1982, 171). The investigators concluded that obviously there are many different types of deficits in dyslexics but it seems that the deficits connected with processing rapidly presented stimuli are more likely to occur in dyslexic individuals with concomitant language deficits. This would explain the results of their later studies, since the dyslexic children of this study may have been those whose deficit is evident in the comprehension of written language but not so much in writing and reading.

Reed (1989) extended Tallal's studies by investigated dyslexics'[2] ability to perceive rapidly presented verbal stimuli as well as nonverbal stimuli. Her experiments comprised among other things the same TOJ task used in Tallal's experiments and the nonverbal stimuli was very much like that of Tallal. Her results showed that dyslexic children differed from age- and sex- matched

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1 The subjects in the dyslexia group had at least 85 on the performance scale of the Wechsler Intelligence Scale for Children-Revised), a reading age (Determined using Gates-MacGinitie Vocabulary and Comprehension Reading Test, and the Gates-McKillop Knowledge of Words Subtest) at least a year below both mental age and chronological age, and a language age (the Carrow Test for Auditory Comprehension of Language, The De Renzi and Vignolo Token Test, the Boehm Test of Basic Concepts, the auditory association and auditory reception subtest of the Illinois Test of Psycholinguistic Abilities, the vocabulary subtest of the WISS, Lee Developmental Sentence Scoring And the Lee Northwestern Syntax Screening Test) no more than nine months below chronological age. The control subjects were tested by the above test as well but they had to fall within six months of chronological age on both reading an language tests. Subjects were matched for age, IQ, and socio-economic status. (Tallal & Stark 1982, 167-168.).

2 The subjects in the dyslexia group scored in the 22nd percentile or below (mean percentile score of 10) on the reading subtest of the WRAT. The subjects of control group scored at or above 40 the percentile on the WRAT (M percentile score was 57). Subjects in neither group displayed sensory, cognitive or emotional problems. (Reed 1989, 274.)

controls in making temporal order judgments with very brief tones and with CV syllables with stop consonants at short interstimulus intervals. Interestingly, the groups did not differ in the discrimination tasks with vowel stimuli presented either with or without white noise. She suggested that poor performance in tasks involving the tones and stop consonant syllables may be due to difficulty in processing very brief auditory cues. Similar conclusions had been made earlier by Tallal and Stark (1983) who found the same tendencies in language delayed children. However, Reed's results did not support Tallal's (1980) claims of a deficit in processing rapidly presented nonspeech stimuli in dyslexics since her results indicated that dyslexics had difficulties in categorising nonspeech as well as CV syllables also at the long ISIs. Further support of the hypothesis that dyslexics may have a deficit in processing brief auditory cues is provided by Reed's results, which revealed that the dyslexics were also significantly poorer than controls in word identification tasks in which only the place of articulation of the initial stop consonant varied. In discussing the possible implications of her results, Reed (1989, 287) did not dismiss the possibility that they may have reflected memory deficits in processing temporal sequences of stimuli containing tones and consonants. Furthermore, she considered it plausible that the results reflected dyslexics' fuzzily defined phonological categories since they were less consistent in identifying syllables near the category boundary as well as in discriminating syllable pairs across the boundary. All of Reed's explanations regarding the results appear plausible but in light of these results in which dyslexics did not have difficulties just with consonants but also with tones, it could be suggested that the dyslexics had problems with processing auditorily brief information regardless of the nature of the stimuli (the vowel stimuli was considerable longer in her experiments than the tones and the "consonant segment" of the CV syllables). Further, whereas it is possible that the dyslexics had difficulties in perceiving the variations of formant frequencies which occurred briefly due to the shortness of the stimuli, the results could also be explained by the fact that the dyslexics may have had difficulties perceiving those particular formant frequency differences that the stimuli were made of.

Farmer and Klein (1993) also used the same type of TOJ task as had previously been used in the studies of Reed as well as Tallal. The results showed that dyslexic adolescents[1] were significantly less accurate in the TOJ task with varying ISIs separating two tones. Unfortunately this report of the study[2] does not provide sufficient information to establish whether there was also a group difference in the stimuli presented with longer ISIs. Farmer and Klein also reported similar results in the auditory fusion task with clicks as stimuli. They (1993, 341) concluded that these dyslexic adolescents seemed to have a temporal processing deficit with rapidly presented auditory stimuli.

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1 The two groups of subjects differed significantly in the grade equivalent in reading level (measured by the Wide Range Achievement Test-Revised), 3B grade level for the dyslexics and 8E for the controls. (Farmer & Klein 1993, 339-341.)

2 The experiments formed a part of Farmer's doctoral dissertation and it is likely that she gave detailed descriptions of the experiments in that work but because the book has not been published I was unable to check on the details.

Interestingly, however, they found also that the dyslexics were not less accurate at a same-different task with sequences of four tones as stimuli presented with various ISIs. Although Farmer and Klein made a weak attempt to explain these results by speculating that the subjects may have processed the sequences holistically rather than sequentially, this would seem to contradict the other evidence of their study.

Kinsbourne, Rufo, Gamzu, Palmer & Berliner (1991) studied auditory temporal processing in adult dyslexics also by means of a TOJ task with varying ISIs. Their TOJ task involved determination of the ear to which one of two short clicks was presented via earphones. The results[1] indicated that dyslexics were significantly inferior compared to controls in the TOJ task. Unfortunately, their report did not indicate what was the specific durational difference in the ISI when the difference occurred between the subject groups. The performance of the dyslexics may have been affected by difficulties with the cross-hemisphere transfer of information, although there exists some experimental evidence (May, Williams & Dunlap 1988) which undermines this explanation. Kinsbourne et al. (1991) provided evidence of results similar to those of the auditory TOJ task using visual stimuli. Since there seemed to be a group difference in the TOJ tasks with auditorily presented nonverbal stimuli and visual stimuli, as well as similar results with other neurophsychological and neuromotorical tasks, the investigators claimed that these adult dyslexics had continuing neurological impairment.

The most recent study using TOJ tasks with varying ISIs using dyslexic subjects[2] is that of Mody, Studdert-Kennedy and Brady (1997). In three experiments they studied the abilities of carefully selected dyslexic children and their matched controls to judge the presentation order of both syllables (/ba/-/da/,/ba/-/sa/ and /da/-/ʃa/) and nonverbal tones (sine tones with identical durations and frequency trajectories of F2 and F3 of the /ba/-/da/

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1 The results of Kinsbourne et al. (1991) were tested for their reliability by comparing the results of all the tasks on all the subjects between the first test and a retest which was conducted no earlier than seven days after the first test. All the test-retest reliabilities were shown to be statistically significant in dyslexics and controls.

2 All the subjects' reading abilities were assessed with the Word Attack and Word Identification subtests of the Woodcock-Johnson Mastery Test-Revised (Woodcock 1987). The dyslexics were at least five months behind midyear grade level in their reading ability and the controls were at least five months above grade level. The IQ levels were estimated by the Peapody Picture Vocabulary Test-Revised (PPVT-R) (Dunn & Dunn 1981) and by the Block Design subtest of the Wechler Scale for Children-Revised (WISC-R) (Wechsler 1974) with in the normal range (scores 80-120) and an attempt was made to match these between the two subject groups. In the dyslexia group only those subjects were chosen who made a minimum of three errors out of 36 trial on the three short ISIs (the similar test was employed in Tallal 1980) combined, and in the control group only those subjects who made no errors in this inclusion TOJ test. All subjects has similar socio-economical family backgrounds, they were monolingual native speakers of English and they all of their hearing was tested to be normal. (Mody et al. 1997 209-211.)

stimuli[1]). The results of the TOJ task with the /ba/-da/ contrast demonstrated that the dyslexics were significantly worse than the controls at short ISIs (100, 50 and 10 msec). In contrast, the results of the TOJ tasks employing the other syllables with exactly the same variations of ISI as well as those TOJ tasks employing the sine wave signals did not indicate any statistical differences between the performances of the two subject groups. Mody et al. interpreted their evidence as showing that dyslexics did not have difficulties in TOJ in general, and that the dyslexics' difficulties identified in the /ba/- /da/ task were due to the phonetic similarity of the stimuli, not to the temporal demands of the task.

Several important factors in their study should be emphasised. Firstly, that the selection of the subjects was biased insofar as only those dyslexics that made errors in the TOJ with the /ba-/da/ contrast task were included in the study. Furthermore, those control subjects who made errors in that particular TOJ task were excluded from the study[2]. Mody et al. (1997,223) acknowledged this factor but defended their choices by stating that they attempted to study the same aspect as in the influential study of Tallal (1980) by selecting subjects who had had problems with the same stimuli as were used in this study and which had been shown to effectively differentiate the dyslexics from the controls. Another unfortunate factor of their study is that the screening criteria for the dyslexics allowed children who were only half a year behind their grade level to be included in the study. In this way the results of their study are more limited as to their generalisability than they could have been had the screening criteria followed more closely the standard in dyslexia studies (i.e., the dyslexic subjects are usually at least a year behind the grade level and most of the time even two years behind). As it is, the dyslexics included in their study could not necessarily been considered severely dyslexic.

The two studies by Watson et al. (1992, 1993) investigated adult dyslexics' ability to discriminate differences in duration in nonverbal stimuli in which the duration of the interstimulus interval was changed. In both of these studies identical pulse discrimination tasks were conducted. Watson (1992) found that there was no group difference between the performance of dyslexics and controls in this task. The results of Watson and Miller (1993) support the finding of Watson (1992). Watson (1992 referring to Leek and Watson 1984 and Watson 1987) noted herself that the pulse-train discrimination task utilised here did not test only the discrimination of duration but rather was more demanding by testing the discrimination of changes in the temporal sequences of repeated stimuli (i.e., rhythm discrimination). In both of these studies also TOJ tasks were utilised with varying stimuli durations but since the formant

1 Although the sine waves were constructed to imitate the syllable contrast between the /ba/- /da/ stimuli used in their study, the perceptual impression was not that of speech.

2 Mody et al. noted that the performance was not normally distributed in either of the subject groups in the TOJ tasks with the /ba/-/da/ stimuli. Mody et al. themselves concede that even the error level of the dyslexic children (3/36 , 8%) was not as high as it could have been but since the control children selected did not make any errors the difference between the subject groups was apparent.

frequencies also changed between the stimuli, these tasks do not provide direct evidence on the perception of duration in dyslexics.

Related to Watson's studies, Zurif and Carson[1] (1970) as well as McGivern, Berka, Languis and Chapman[2] (1991) studied the auditory processing of temporal patterns in dyslexic and control children by means of a rhythm test[3]. The task was to judge whether two rhythmic patterns with several beats tapped out in quick succession were the same or different. The results of both of these studies showed that the dyslexic children were significantly worse in this task than the controls. Furthermore, Zurif et al. (1970, 359) found also significant differences between the performances of the same dyslexic and control subjects in processing temporal patterns visually. Since neither of the reports included details of the stimuli durations and more importantly about the interstimulus intervals, the affect of specific durations to the results cannot be assessed. What is evident, though, is that the evidence on rhythmical perception in dyslexics is still somewhat controversial on the basis of these results, since the results of Zurif et al. and McGivern et al. do not agree with those of the two studies of Watson. Although this controversy is most likely due to the methodological differences between the studies there needs to be more experimental evidence on the rhythmic abilities of dyslexics before further conclusions can be made.

The investigation of Hari and Kiesilä (1996) forms an exception among the studies reviewed here by studying the perception of durational differences in Finnish speaking subjects as opposed to all the other studies which had speakers of English as subjects. This is a significant factor to the present study since all of the subjects in it are native speakers of Finnish. Hari and Kiesilä investigated the temporal processing of duration in dyslexic adults[4] by using trains of binaural clicks as stimuli. These trains of clicks with short interstimulus intervals created the illusion that the clicks were moving from one side to another (from right to left or vice versa). Ten adult dyslexics and twenty normal readers served as subjects. The task was to judge the direction

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1 All the subjects reading level (tested with the Gates Reading Test), arithmetical ability (tested with the Stanford Arithmetic Test) and IQ level (tested with the Henmon Nelson Test of Abilities) and visual ability were scored. Only the difference in the reading skills between the groups were significant. (Zurif & Carlson 1970, 353)

2 The subjects in the dyslexia group opposite to the subjects in the control group were reading at least one grade level below normal and exhibit phonetic or written letter reversals as noted by teachers. All the subjects were tested for normal intelligence level (as measured by Test of Academic Ability, Short Form, and in the case of 1st graders the evaluation was based on teacher report) and for normal hearing (as measured by basic acuity tests). (McGivern et al. 1991,59-60.)

3 Both of these studies utilised the Seashore Rhythm Test which is a subtest of the Halsted-Reitan neurological assessment battery (Halstead 1947).

4 The dyslexic subjects had a history of difficulties in learning to read and spell. In addition, the dyslexic subjects were significantly poorer in several phonological processing tasks abilities (measured by the following tasks: digit span forwards, backwards, rapid stimulus naming and oral reading speed).

of the clicks in a scale of 20 steps[1]. The ISI's between the clicks ranged from 45 to 500 msec. The results indicate that the illusion of sound movements disappeared at time intervals exceeding 90 to 120 msecs in controls. The corresponding time interval between clicks was larger in dyslexics: the illusion ceased at the intervals 250 to 500 msec. Statistical analysis of the data revealed that the difference between groups was highly significant at the larger ISIs (150, 250 and 500 msec) when the controls ceased to perceive the moving illusion while most of the dyslexic subjects still perceived left-to-right saltation. Hari and Kiesilä (1996, 139) interpreted their results as providing evidence of a deficit in the processing of rapid sound sequences in dyslexics. Again the relevance of studies like theirs to speech perception and dyslexia can be questioned on the basis of the stimuli. However, the results of this study are striking as such and therefore this study can be seen as providing compelling support to the claim that there is a temporal processing deficiency in dyslexics.

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1 The twenty values of the scale between all the subjects were normalised to correspond the whole scale from left to right.

TABLE 2 Dyslexia studies involving perception of durational differences in the interstimulus interval.

Study	Age of subjects (years; months)	Number + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Farmer & Klein 1993	dyslexics; M = 14; 07, controls; mean14; 10	20 dyslexics, 20 controls	a click fusion task	?	clicks	?	?	yes
		males? females?	temporal order judgement	?	high and low tone	?	360, 120, 40	yes
			sequence matching S/D	?	two sets of four high/ low tones	?	360, 120, 40	no
Hari & Kiesilä 1996	dyslexics; 26-38 years (M= 30; 6), controls; 22-46 (M= 29; 8)	10 dyslexics; four males, six females 20 controls; 11 males, 9 females	directional hearing illusion (left-right)	marking a response in the answer sheet (scale from 1 to 20)	8 different trains of binaural clicks with small inter-aural time differences	1	500,250, 150,120, 90,75, 60,45	yes in ISIs 150-500

TABLE 2 (Continues)

Study	Age of subjects (years; months)	Number + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Hurford & Sanders 1990	8 and 10 year olds in both groups	8 year olds; 14 dyslexics, 9 males, 5 females. 13 controls; 9 males, 4 females 10 year olds; 11 dyslexics, 8 males, 3 females 14 controls; 11 males, 3 females	discrimination	pressing one of the two buttons (red colour indicating that the stimuli were excactly the same. blue for not)	/bi/,/di/ and /gi/	160	400,320, 240,160, 80,20,10	yes; between 8 year old dyslexics and controls with ISIs of 80, 20, and 10; no; between 10 year olds
Kinsbourne, Rufo, Gamzu, Palmer & Berliner 1991	dyslexics 29; 3, controls 26; 5	26 dyslexics 21 controls	temporal order threshold (determines the right-left directional order)	?	clicks	1	initially 20 then with 20 increments until a 90% criterion of order judgements accuracy reached	yes

TABLE 2 (Continues)

Study	Age of subjects (years; months)	Number + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
McCroskey, & Kidder 1980	7, 8, 9	45 dyslexics; 25 males, 20 females, 45 controls; 23 males, 22 females 7 year olds; 15 dyslexics, 15 controls; gender? 8 year olds; 15 dyslexics & controls, 9year olds; 15 dyslexics & controls	discrimination (one or two tones)	pressing a switch	270 pairs of puretone pulses	17	40,30, 25,20, 15,10, 5,2,0	yes
McGivern, Berka, Languis & Chapman 1991	6; 7-12;2 (n= 6-6), 6; 7-8; 0 (n= 9-19), 8; 1- 10; 0 (n= 9-10) 10; 1- 12; 2	24 dyslexics; 15 males, 9 females 26 controls; 15 males, 11 females	discrimination of rhythmical patterns (same-different)	?	30 patterned tones	?	?	yes

TABLE 2 (Continues)

Study	Age of subjects (years; months)	Number + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Mody, Studdert-Kennedy & Brady 1997	7;0-9;3	20 dyslexics, 20 controls	identific-ation	verbal answer and pointing a red dot for /ba/ and a green dot for /da/	/ba/ and /da/	250 each	400	yes (when the results of the three tasks were combined)
			the same as above	the same as above	/ba/ and /sa/	250 /ba/ 400 /sa/	400	no
			the same as above	the same as above	/da/ and /ʃa/	250 /da/ and 400 /ʃa/	400	no
			temporal order task	pointing one of two different coloured dots	/ba/ and /da/	see above	100,50, 10	yes with 100 and 10
			the same as above	the same as above	/ba/ and /sa/	see above	100,50, 10	no
			the same as above	the same as above	/da/ and /ʃa/	see above	100,50, 10	no
			discrimin-ation (S/D)	pointing two dots of the same colour for "the same" and two different for "the different"	/ba/ and /da/	see above	400	yes

TABLE 2 (Continues)

Study	**Age of subjects (years; months)**	**Number + gender**	**Task**	**Response required**	**Stimuli**	**Duration of stimuli in msec**	**ISI in msec**	**Significant group differences?**
Mody, Studdert-Kennedy & Brady 1997	7;0-9;3	10 dyslexics 10 controls (a sub-group)	discrimination (S/D)	pointing two dots of the same colour	/ba/ and /sa/	250 /da/ and 400 /ʃa/		no
		10 dyslexics 10 controls (a sub-group)	see above	see above	/da/ and /ʃa/	see above		no
		20 dyslexics, 20 controls	identification	pointing upward or downward pointing arrows	sine waves (2nd and 3rd formants of /ba/-/da/)	250 each	400	no
			discrimination	see above	the same as above	the same as above	100,50, 10	no
Reed 1989	7 ; 9 -10; 4 (M=9 yrs in dyslexics) (M= 8 yrs 11 m in controls)	23dyslexics, 23 controls with 6 girls, 17 boys in each group	temporal order task	pressing one of two coloured keys in the order of	tones	75	400, 300, 150, 50, 10 msec	yes
			see above	see above	/ɛ/-/æ/	250 each	see above	no
			see above	see above	/ba/-/da/	250 each	see above	yes

TABLE 2 (Continues)

Study	Age of subjects (years; months)	Number + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Reed 1989	7 yrs 9 months- 10 yrs 4 m ?? (a sub-group)	10 dyslexics 10controls gender?	temporal order task	?	/ɛ/-/æ/ with 12 dB of white noise	250 each	400, 300, 150, 50, 10 msec	no
Tallal 1980	dyslexics 8-12 (M=9; 7) controls (M=8; 6)	20 dyslexics; 16 males, 4 females. 12 controls; 6 males, 6 females	temporal order task	pressing one of two identical panels (one above the other)	computer-generated complex tones (tone 1 100 Hz, tone 2 302 Hz)	75	428	no
			rate order	the same as above	the same as above	75	305, 150, 60, 30, 15,8	yes
			temporal order task	(side by side)	the same as above	75	428	no
			discrimin-ation (same-dif-ferent)	(side by side)	the same as above	75	428	no
			discrimin-ation with various rates of present-ation	the same as above	the same as above	75	305, 150, 60, 30, 15, 8	yes

TABLE 2 (Continues)

Study	Age of subjects (years; months)	Number + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Tallal & Stark 1982	dyslexics 7;5 - 9 ; 2 (M=8 ; 2) controls 7 ;7 - 9 ; 1 (M= 8 ; 3)	26 dyslexics; 22 males 4 females. 16 controls; ? males ? females	temporal order task (TOJ)	pressing one of two identical panels (one above the other)	computer-generated complex tones (tone 1 100 Hz, tone 2 302 Hz)	75	428	no
			TOJ with various rates of presention	see above	see above	75	305, 150, 60, 30, 15, 8	no
Watson 1992	college students	20 dyslexics 25 controls	pulse discrimination	?	tone 1 kHz	20	40 (standard) 40-90 (variations)	no
Watson & Miller 1993	dyslexics M=24 controls M=22	24 dyslexics; 16 males, 8 females 55 controls; 20 males, 35 females	temporal processing (pulse) discrimination	?	tone 1 kHz	20	40 (stand-ard) 40-90 (vari-ations)	no

TABLE 2 (Continues)

Study	Age of subjects (years; months)	Number + gender	Task	Response required	Stimuli	Duration of stimuli in msec	ISI in msec	Significant group differences?
Zurif & Carson 1970	grade-four level children (appox. 9 year olds)	14 dyslexics, all males 14 controls, all males	temporal processing, same-different discrimination	verbal response whether the 2 stimuli patterns were the same or not	tapped sounds	?	?	yes
			the same as above, auditory-visual matching	choose between 3 dot patterns corresponding to the auditory pattern	clicks	?	?	yes

3.2.3 Some aspects affecting the outcome of the studies on duration, and the hypothesis of the current experiments

As is perhaps evident from the above review, there is no consensus on the temporal processing abilities of dyslexics. This is due to many factors which may have a decisive influence on the outcome of the experiments. In the following section a brief survey of the evidence reviewed above is presented with some speculations as to the reasons for the outcomes of some of the studies. All this information facilitates the formulation of the hypothesis for the two experiments of this chapter.

The nature of the stimuli, in the extent to which they were comprised of speech or nonspeech, did not appear to influence the results of the studies to any noticeable extent. Scarcely more than half of the studies (53%) using nonspeech stimuli showed that dyslexics were inferior to controls in the perception of the durational features of the stimuli. It should be noted that the majority of the studies reviewed here utilised nonverbal stimuli. In contrast, the studies employing speech stimuli were scarce. These studies indicated that in just over half of the cases (54%) the dyslexics were worse than the controls in perceiving durational differences in speech stimuli. Therefore, it is by no means clear if dyslexics differ from controls in perceiving durational characteristics of speech stimuli or if their deficits are evident in the processing of more basic auditory stimuli or if both of the domains are affected. What seems quite clear is that all except one (Hurford et al. 1990 being the exception) of those studies which found some temporal processing deficits in dyslexics showed that only a part of the dyslexic population displayed signs of the deficit.

One of the important factors in assessing experimental evidence is to pay attention to the means by which the data has been collected together, especially regarding the nature of the stimuli. Discrimination tasks (SD and ABX) with stimuli of variable duration yielded more results (five out of eight[1]) according to which there was no difference in the performance of the dyslexics when compared to the controls. In addition, one of the remaining three experiments (Watson 1992), with positive results as to the existence of a deficiency in discriminating durational differences, was replicated later with opposite results (Watson and Miller 1993). Thus, there does not seem to be clear evidence either for or against the possible inferiority of dyslexics in discrimination tasks with temporal parameters.

As for the discrimination tasks in which the durational variations were located in the interstimulus intervals of stimuli (all of them with nonspeech stimuli), the results appear to be in no agreement either. Five experiments out of nine showed that dyslexics are inferior in discriminating stimuli which are presented with a short interstimulus interval. Two of these discrimination tasks consisted of discrimination tasks using relatively long rhythmic patterns, and thus, they do not provide direct evidence on the ability to discriminate

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1 The results of Brandt and Rosen are not included here since they did not specifically report statistical figures on the data.

durational differences. Thus, although the evidence is somewhat inclined to show deficiencies in dyslexics in this respect this aspect should be studied further to confirm these results.

In the scarce identification tasks the results are also divergent, sixty percent of them indicating a deficiency in dyslexics. In the only two identification tasks (Reed 1989, Hurford & al. 1990) in which the ISIs were varied, the results indicate a difference in performance between dyslexic and control subjects: all the stimuli were less consistently identified by dyslexics when compared to controls when the ISIs were relatively short. However, in Hurford et al' s study (1990) there was not a statistically significant difference between the older dyslexics and their age matched controls. Since the experimental evidence is divergent in this respect more information is needed in elucidating these abilities of dyslexics. The current study deals specifically with the identification of speech stimuli, and, thus, by testing the ability to categorise speech stimuli according to durational changes more evidence on the identification skills of dyslexics is provided here.

The results of the TOJ tasks with variable durations of ISIs are also divergent, six of the ten tasks producing positive results indicating significantly poorer performance in dyslexic subjects in comparison to that of controls. Among the evidence are Tallal's two experiments which yielded contradictory results using exactly the same method in both experiments but with different subject groups. Also, the nature of the stimuli affected the performance in Reed's studies indicating that the briefness of the perceptual cues may cause difficulties for dyslexics in perceiving the order of presentation of the stimuli. It seems that the nature of the stimuli affected the performance of the dyslexics in this task and there seems to be a subgroup of dyslexics which are, in particular, poorer in the task with durational changes of ISIs.

It is important also to pay attention to the demands of the different types of task for the subjects. The TOJ tasks do not provide evidence on mere identification or discrimination of the stimuli since also the sequential order of the stimuli needs to be processed. Thus, some level of memory load is also present in the performance of a TOJ task. The auditory discrimination of stimuli on the other hand means that listeners have to detect a difference between two or more stimuli. In the case of speech stimuli, the criterion according to which the decision is made can be based on either the purely physical (i.e., durational) side of the stimuli or to the phonological side (i.e., durational differences which goinside with phoneme categories of the particular language in question), or both of these. Auditory identification means that listeners have to identify one stimulus or more, i.e. they have to label them. If the listeners are given two choices (as was the case in virtually all of the identification tasks reviewed) then they are forced to identify the stimuli as one of the provided responses: The forced choice identification tasks also imply that the listener can discriminate the difference between the two choices either acoustically or phonologically or both. The two experiments of this chapter comprise categorisation tasks: the experiment with adult subjects is a forced choice categorisation task whereas that of infant subjects can be considered a categorisation task in which the choices of responses are not provided directly. The question of the nature of the tasks will be returned to later on in the *Methods* part of this chapter.

As can be seen the comparison of the results is by no means easy and it is made even more difficult and even futile by the fact that the selection criteria for the dyslexic groups varied significantly between studies (e.g., Pallay did not test severe dyslexics, Tallal and Stark's dyslexics were deviant particularly in their comprehension abilities, Steffens et al. studied compensated dyslexics, etc.). Also the age of the subjects varied a great deal between the studies, which has implications for the interpretation of the results. In addition, there appears to have been a good deal of variability in the performance of the individual dyslexics in various tasks. Therefore, the selection criteria should be rigorous and similar between studies and only then could the results of different studies be comparable between similar tasks using similar stimuli.

One factor that surfaced from the investigation of these dyslexia studies, however, is that it appears that if there exist dyslexics who differ in the auditory processing of the temporal features of stimuli, it seems that they have specific problems dealing with stimuli that are short in duration or that are presented with short ISIs (McCroskey & Kidder 1980, Tallal 1980, Pallay 1986, Reed 1989, Hurford & Sanders 1990, Steffens et al. 1992, Farmer & Klein 1993, Hari & Kiesilä 1996): When the ISIs get sufficiently long or the stimuli cues are longer in duration the perception abilities of the dyslexics and controls became similar. It is important to notice, however, that several of the studies (Reed 1989, Hari & Kiesilä 1996) indicated that the performances of the two subject groups differed also in the longest durations of ISIs, dyslexics being inferior to the controls. According to the majority of the results of previous studies it could be hypothesised that in the current experiments the dyslexics would differ from the controls in the categorising of the stimuli in cases in which the duration of a stop closure belongs to the shorter end of the durational continuum. In other words, previous experimental evidence indicates that dyslexics in comparison to nondyslexics may need longer durational differences between stimuli in order to categorise them differently. This hypothesis will be tested in the two perception experiments of this chapter.

3.3 Experiment 3

3.3.1 Research questions

The objective of Experiment 3 was to investigate the ability of Finnish adult dyslexics to categorise sounds into two quantities according to their duration. Experiments 1 and 2 indicated that the stimuli with varying duration of a stop closure was perceived categorically by adult listeners. Experiment 3 utilised the same stimuli as was used in Experiment 1. Earlier studies on dyslexics (McCroskey & Kidder 1980, Tallal 1980, Pallay 1986, Reed 1989, Kinsbourne et al. 1991, Steffens et al. 1992, Watson 1992, Farmer & Klein 1993) have indicated that dyslexics may have problems with the perception of duration. The findings of the earlier investigations (Tallal 1980, Pallay 1986, Steffens et al. 1992, Watson 1992) also suggested that dyslexics are heterogeneous as a group in tasks of temporal processing. Experiment 3 was designed to elucidate some of the aspects of the earlier findings and, therefore, answers were sought to the following research questions:

1. Is there a difference between dyslexic adults and control adults in the quantity categorisation of the pseudoword *ata* with varying duration of the stop closure?

2. If there is, how is this difference manifested? Or more specifically, in which duration/s does the difference emerge between the subject groups?

3. Is there a difference between the subject groups in the location of the category boundary in the durational continuum between the two quantity categories?

4. Is there a difference in the bandwidth of the category boundary in the durational continuum between the subject groups?

5. Is there a difference between the two sexes within the dyslexia group and within the control group?

6. Are there individual differences in the categorical functions?

7. Are there differences in terms of the reaction times of the responses in the dyslexic adults and the control adults?

8. Are there differences in the categorical functions and reaction times in the first-time trial data?

3.3.2 Method

3.3.2.1 Subjects

Altogether 133 adults participated in Experiment 3. All of these adults were parents who had a baby in the Province of Central Finland in the years 1993-1996. Fifty-seven of the adults were diagnosed as dyslexic individuals and 76 of them were diagnosed as having no problems in reading or writing. Thirty-three of the dyslexic subjects were female and 24 were male. The corresponding figures in the control group were 40 and 36, respectively. The ages of the subjects ranged from 21 to 47 the mean age being 33 years 5 months for men and 31 years and 8 months for women[1]. The mean time span of formal education was 11 years in both of the subject groups. The socioeducational status of the subjects was representative of the distribution of the Finnish population and an attempt was made to match the socioeducational background of the subjects in the two groups[2]. All the subjects in both groups reported that they had normal hearing and that their speech was not deviant. Furthermore, none of the subjects had any prior experience with the test paradigm applied in the present study. The subject sampling for the dyslexia group and for the control group plays a significant role in the present study and, therefore, the different features of the sampling are described in detail next (this text on screening criteria has been adapted from the thorough description written by the researcher, Seija Leinonen, who is responsible for the adult screening in the dyslexia projects, see Leinonen, Leppänen, Aro, Ahonen & Lyytinen 1998).

Screening Criteria

There exist no standardised tests yet for the identification of dyslexia in Finnish-speaking adults. The methods for screening dyslexics were developed by the psychologists[3] in the project "Jyväskylä Longitudinal Study of Dyslexia". Furthermore, since the subjects belonged to the longitudinal studies of genetic dyslexia, it was also

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1 The age of the adults was determined by the date on which they participated in the laboratory tests of the project.

2 An attempt was made to match the socioeducational background in the subjects groups, but, for practical reasons, it was necessary to make some concessions. Firstly, in a relatively small area of Finland there were not an abundance of dyslexic adults who were expecting a baby during the three year data collection time span. Secondly, the criterion according to which also the control adults had to have had a baby between 1993 and 1996 and the fact that these families with babies had to be willing to take part in such a long term project imposed limitations on the matching of the socioeconomic backgrounds of the volunteering families.

3 Most of the planning of the screening tests was done by Seija Leinonen, Sari Havu and Heikki Lyytinen, the first of these also executing most of the tests together with Merja Nikula.

crucial to obtain information on difficulties in reading and/or spelling among relatives. The screening processes for both the subject groups were executed in three different stages which are described below.

Three stages of screening

Stage I: A short questionnaire pertaining to difficulties in learning to read or spell in parents and in their close relatives were given to parents who visited maternity clinics[1] between 15th to 20th pregnancy weeks.

Stage II: Approximately 9000 babies were born during 1993-1996 in central Finland. In the end there were almost 3000 families who were interested in the dyslexia projects. An extensive questionnaire pertaining to demographic information was mailed to those 3000 families. Questions dealt with the subjects' childhood, adulthood and relatives. The questions about childhood were concerned with the following aspects: details on childhood problems in reading and spelling, time delay in learning to read and spell when compared to the children of the same age, the contribution of these difficulties to achievement in school, and attendance to remediation (whether remedial help was received) in reading and spelling or in articulation. At least two responses indicating problems in the above questions were required for selection to the next screening stage for the dyslexia group.

The problems in adulthood were screened by questions pertaining to the following aspects: difficulties in reading or spelling, for example, reversal of letters and/or numbers or slowness in reading. The subjects were screened for the prerequisites of familial dyslexia in questions about reading or spelling difficulties in close relatives. The criterion for inclusion in the dyslexia group in this respect was that at least one of the close relatives, for example, the subjects' own school-age child, a parent, a sibling, an aunt or an uncle, had problems in reading or spelling. If this information was unclear on the basis of the questionnaire, all the inconsistencies were checked in separate interviews. Furthermore, those relatives who had not had an opportunity to participate in obligatory schooling, which was introduced in Finland in 1928, were not counted as dyslexic relatives. Dysphasic individuals[2] were not included in the sample either as subjects or as dyslexic relatives. Subjects were not excluded from the sample if they reported problems only with the

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1 In Finland virtually all pregnant women visit a maternity clinic and often the child's farther comes along and therefore it can be assumed that if not all then virtually all expecting parents with dyslexia in central Finland were able to get information on the dyslexia research projects.

2 Dyphasics were defined in this study as those who reported delay in their speech development, with significant stuttering, slowness or unclearness in articulation.

articulation of single phonemes (e.g., /r/ or /s/ or /l/) for which they had received speech therapy or remediation.

Stage III: The parents whose information conformed with the selection criteria of the two previous stages were invited to the university for further diagnoses of dyslexia with a familial background. In addition, those parents who intended to participate in the study as control adults were tested in the university. To diagnose dyslexia in adulthood a comprehensive battery covering the domains of oral text reading, spelling and word recognition was constructed for the purposes of the dyslexia projects. All the tasks included in the diagnosing of dyslexia are described below after a short description of the general procedure.

Procedure in the third stage of screening

Each subject completed an interview in the university as well as all of the tasks in a single three-hour session. The task sessions were conducted in a large room the door of which was sound-attenuated. The computer-aided tasks were administered using an Amiga PC computer. Experimental audio stimuli were presented using headphones (Sennheiser HD 25-1) at an amplitude of 60 dB. The subjects responded to the stimuli by speaking into a microphone which was attached to the headphones, or by pressing one of two clearly marked buttons. Experimental visual stimuli were presented on a computer monitor which was placed approximately 50 cm away from the subjects. The subjects indicated their responses to the visual tasks by pressing one of two buttons. The order of tasks was the same for all subjects: the interview, the Raven tests, the computer-aided tests of reaction time 1 and 2, the hyphenation task, the nonsense word (oral) reading task, the phonological lexical decision task, the auditory verbal short-term memory task, the visual verbal short-term memory task, the orthographic (oral) reading task, the orthographic lexical decision task, the phoneme deletion task, the syllable reversal task, the rhyming 1 and rhyming 2 tasks, the reaction time 1 and 2 tests, the written spelling task and the oral text reading task.

Tasks employed in the third stage of screening

1. *Oral text reading:* Subjects read aloud two passages of text, which were recorded on an audio cassette. The first text passage included 218 words and the second 128 words. Subjects were given spoken instructions to read each passage as fluently and accurately as they normally do. Four multiple-choice questions were asked after each text passage, but accuracy in comprehension was not taken into account in the selection of subjects. The number of errors were counted and the duration of the reading time was measured.

2. *Spelling*: Subjects were asked to spell on dictation ten nonsense words (seven pseudowords and three nonwords) and ten words with 6 to 14 letters and with 2 to 7 syllables. The stimuli were presented via headphones and subjects had no time-limit to complete the task. If necessary, the subject could hear each stimulus twice. Each subject received three z-scores, one for the total number of errors in spelling, which was used for diagnosing dyslexia. Two other z-scores, one for the number of errors in spelling nonsense words and the other for the number of errors in spelling words were obtained for more detailed analyses.

3. *Word recognition skills* were tested in five separate tasks, which were Finnish modifications of the tasks employed by Høien and Lundberg (1989) and Seymour (1986). After the instructions, subjects received two to four training trials, in which incorrect responses were corrected by an examiner. Subjects were encouraged to respond as quickly as possible while attempting to be accurate. Each stimulus was preceded by a warning signal[1]. Response latencies were measured from the stimulus onset to the response onset. In articulation tasks the naming latencies were measured by a voice key. In lexical decision tasks subjects responded by pressing one of the two buttons. A mean reaction time for correct responses was calculated. The five tasks designed to measure word recognition skills are described below.

a. The test battery included two tasks which measured phonological recoding skills. The first one was *a nonsense word (oral) reading task*. Thirty pseudowords and thirty nonwords with 4, 6 and 8 letters and 2 to 4 syllables were used as stimuli. The stimuli were presented on a monitor. The subjects read aloud each stimulus using a voice-key. A new stimulus was presented after an answer or no later than 10 seconds after the stimulus presentation. The subjects' responses were recorder on audiotapes for later analysis of errors. The number of correct responses was measured and the mean response latency of correct responses was calculated.

b. The second phonolgocial recoding task was *a phonological lexical decision task*. Fifteen words and the same number of pseudowords with 12 to 22 letters and five to nine syllables were used as stimuli. An inflected form of each stimulus was presented. The inflected pseudowords were constructed by adding an ending which was not grammatically acceptable. Stimuli were presented on a monitor and subjects indicated if the stimulus was a pseudoword or a word by pressing one of two buttons on a keyboard. A new stimulus was presented either after an answer or 20 seconds after the stimulus presentation. The number of correct responses was measured and the mean response latency of correct responses was calculated.

1 For visually presented stimuli an asterix appeared on the monitor as a warning signal and for auditorily presented stimuli a tone was presented via headphones.

c. Two tasks measuring orthographic word recognition skills were also included in the test battery. In *an orthographic oral reading task* forty words and twelve nonsense words were used as target stimuli, which were presented tachistoscopically for 80 milliseconds on a monitor. Immediately after each stimulus a mask stimulus was presented. Subjects were asked to name both the target stimulus and the masking stimulus. New stimuli were presented after an answer or after five seconds. Each mask stimulus had as many letters and syllables as the target stimulus, the number of letters being four, six or eight in each stimulus and the number of syllables varying from two to four. Half of the masking stimuli for both the word and nonsense words were words and the other half were nonsense words. The number of correct responses to target stimuli was measured.

d. Another task measuring orthographic word recognition skills was *an orthographic lexical decision task.* The task comprised 21 words and 21 pseudowords with four, six or eight letters with two to four syllables in each stimulus. Each stimulus was presented tachistoscopically for 60 milliseconds on a monitor. Subjects indicated if the stimulus was a word or a pseudoword by pressing one of two buttons on the keyboard. A new stimulus was presented after an answer or after five seconds. The number of correct responses and the mean reaction latency of correct responses was calculated.

e. The test battery also included *a hyphenation task*. The task included 24 words with four, six or eight letters with two to four syllables in each. Half of the words were high-frequency and the other half low-frequency words. Each stimulus was presented in its entirety on a monitor after which they were constructed letter by letter with an interstimulus interval of two seconds. The subjects' task was to indicate the point at which each syllable ended by pressing a button after the last letter of the syllable. In the cases in which the time interval between letters was too fast for subjects the task could be administered manually. The number of correctly hyphenated words was calculated.

In addition to the tasks described above several other computer-aided tasks were administered to subjects. These tasks were designed to measure phonological awareness, verbal short-term memory and basic sensomotoric reactions. Since the z-scores of subjects in these tasks were not included in the diagnoses of adult dyslexics, no further description of these tasks is provided here.

Criteria for the selection of subjects in the dyslexia group

The criteria for inclusion in the third and last stage of screening for the dyslexia group were the following. Firstly, problems in reading or spelling in childhood had to have lasted more than one year after the first grade. Secondly, participation in remediation for these problems was required. If, however, a subject had no opportunity for remediation[1], teachers' or parents' observations of the specific problems in reading or spelling were acknowledged. Thirdly, subjects were required to report continuing problems in reading or spelling in adulthood. Fourthly, at least one relative with reading or spelling problems was a prerequisite. Fifthly, subjects could have no sensoric or neurological abnormalities. Finally, subjects' cognitive capacity was required to be at 85 or above as estimated by the Raven's Progressive Matrices subtests B, C, and D.

Performance in all of the tasks of the third screening stage was converted into standardised z-scores from the mean and standard deviation (SD) of a normative group (N = 100, mean = 0, SD=1) in each variable[2].

The subjects were diagnosed as dyslexics when they had z-scores below or at -1.0 in accuracy or speed in oral text reading or accuracy in spelling both word and nonsense words <u>and</u> in accuracy or speed in two word recognition tasks[3].

Criteria for the selection of subjects in the control group

Subjects for the control group were selected along the same principles as were used in subject sampling of dyslexic individuals, but the criteria for inclusion were naturally opposite in the two groups. Control subjects completed the first two stages of screening to the same extent as the dyslexic subjects had done. The information which the subjects provided on themselves and on their relatives was required not to give any indications of reading or spelling

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1 Nation-wide remediation for difficulties in reading and spelling started in Finnish schools in the mid 1970s.

2 A sample of 100 adults, half of whom were females and the other half males aged between 20 and 40 years, was separately assessed to obtain norms. These subjects were randomly selected from four different educational levels: 20 adults with only basic education (9-12 years) and courses of some months in manual training, 20 adults with basic education and two years of additional education, 40 adults with basic education and three years of additional education, and 20 adults with basic education and at least five years of education in university. The normative sample is intended to represent the educational distribution of Finnish adults between 20 to 40 years of age.

3 Among the individuals tested were 27 individuals who reported a family history of dyslexia as well as difficulties in written language themselves but whose scores, however, fell outside the inclusion criteria for the dyslexia group, i.e., they did not seem to manifest serious difficulties in the tests. These individuals were included in the dyslexia projects as compensated dyslexics. In the present study they were not included in the experiments involving adults. The infants of these adults were, however, included in the infant experiments. The rationale behind this action was that since these compensated adults reported having had serious problems with written text and had a positive history of the condition in their families, their infants were considered to be at risk of being dyslexics. It should be noted that the size of the infant group with a compensated dyslexic parent which was included in the actual testing phase, the categorisation phase, was not large, since only 10 of them managed to pass the criteria for inclusion in the categorisation phase.

difficulties. Individuals with sensoric or neurological abnormalities were not included in the study. In addition, control subjects' cognitive capacity was estimated to be at 85 or above as assessed by Raven's Progressive Matrices subtests B, C, and D.

At the third stage of screening the following tasks were administered on control adults: Nonsense word reading (response latencies and accuracy), orthographic reading (accuracy), accuracy and speed in oral text reading, accuracy in spelling both actual words and nonsense words. The criteria for inclusion in the control group were z-scores at or above -0,9 in all of the variables except one, which could be at -1,0 or below.

3.3.2.2 Stimuli

The stimuli in Experiment 3 comprised the stimuli continuum utilised in Experiment 1 without two of the stimuli of the original continuum (see details of the construction of the stimuli continuum on pages 31-34). Furthermore, the stimuli of the present experiment were utilised in Experiment 4 with young infants. The reason for excluding the two stimuli was that since young infants were tested the experiment needed to be shorter. Stimuli *ata8* and *ata10* were chosen to be excluded from the present stimuli continuum on the bases of the results of Experiment 1. The stimulus *ata9*, which was identified by 100 percent of the adult listeners as "atta", was apparently as good an exemplar of a stimulus with a long quantity stop sound as the original stimulus *atta10* in Experiment 2, and was, therefore, chosen to be the endpoint of the stimuli continuum. *Ata8* which was identified by 98.8 percent as "atta", was dropped from the original continuum since there seemed to be an abundance of stimuli categorised likewise (as "atta") in the continuum as it was. Thus, the stimuli continuum used in the present experiment comprised 8 stimuli (see Fig. 9 below). The stimuli were also divided into two equal size categories according to the identification function[1] in Experiment 1 employing the same stimuli: stimuli 1 to 4 belonged to the short quantity category, the Ata-category, and stimuli 5 to 9 belonged to the long quantity category, the Atta-category.

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1 The level of 80 % of *atta* identifications in Experiment 1 was selected as the point at which the stimuli could be categorised by the majority of the cases as having a long quantity degree in the word medial stop. Respectively, the stimuli which were identified by less than 80% of time as *atta* were categorised as having a short quantity degree.

	ATA-Category				ATTA-Category			
stimuli	ata 1	ata 2	ata 3	ata 4	ata 5	ata 6	ata 7	ata 8
occlusion in msec	95	115	135	155	175	195	215	255

FIGURE 9 The stimuli continuum employed in the perception test in Experiment 3. Duration of the silent closure stage of the word medial dental stop was augmented in stepwise fashion with increments of 20 msec. Natural speech sounds were used as stimuli. The original stimulus was taken from the speech of a female producing the pseudo word *ata*. Altogether 8 stimuli were constructed from the stimulus *ata 1* ranging in total duration from 300 to 480 msec, and the impression of the perceived stimulus shifted from *ata* to *atta*. *Ata 1* was utilised as a standard background stimulus, to which the other stimuli were compared.

3.3.2.3 Apparatus

The experiment was conducted in a small sound-attenuated room. The entire experimental procedure was controlled online by the computer (Amiga Commodore 2000) and custom-designed software (The Event Organiser programme)[1] in the adjoining control room. The stimuli were presented at a 22-kHz sampling rate through an 8-bit D/A converter which was low-pass filtered at 4.8 kHz before going to the loudspeakers in the testing room. The stimuli were played through a Yamaha monitor speaker (MS101), which was situated at a distance of approximately 50 cm from the subjects. The stimuli were presented at 70 dB SPL and the system was calibrated regularly using a Brüel and Kjaer precision sound-level meter (Type 2235). The subjects' responses as well as the response times to the stimuli were indicated by the press of a button[2]. In front of the subjects was located a box with two compartments in which a toy bunny and a bear played drums when the button was pressed during the stimuli presentation of stimuli *ata5* to *ata8*. The animated toys could not be seen until the lights inside the boxes were turned on under computer control. The toys functioned as a reinforcement of the correct responses in the stimuli from the ATTA-category. This function of the toys was not revealed to the adult subjects. Rather, they were told to ignore the animated toys which were lit

1 The Event Organiser®-program is a product of Bits and Chips Ltd. and was designed originally by Seppo Sneck and developed further by Timo Rossi.

2 During the experiment subjects were holding a cone shaped small apparatus in their hand on top of which a response button was situated. The button presses were recorded onto the computer together with the time which had lapsed since the beginning of the observation period, i.e., from the onset of the presentation of the first stimulus in the observation period.

and started to move from time to time[1]. They were told that since their own infants were tested with exactly the same procedure, the same animated toys, which were there to keep the infants attentive, were also included in the adult version of the paradigm.

3.3.2.3 Procedure

The procedure was originally designed for Experiment 4 with young infants as subjects. The reason for using the same procedure in this experiment with the adult subjects was that in this way the extent to which infants' categorisation abilities, which are the main focus of the study, mirror those of adults, could be investigated.

The categorisation abilities of the adults subjects were assessed using a modified version of a conditioned headturning paradigm, originally developed by Moore, Wilson and Thompson (1977) and further developed by Kuhl (see Kuhl 1985b for review). The technique used with the infant subjects in Experiment 4 was modified by changing the method of response from headturns to button presses. In addition, the adult subjects were orally instructed to press the response button as soon as they perceived that the repeated background stimulus *ata* changed to the *atta* stimulus[2]. These oral instructions were also accompanied by a visual demonstration in which the subjects were shown on a piece of paper the possible stimuli sequence used in the experiment[3]. The similarity of the stimuli was emphasised in the

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1 The animated toys started to drum when the computer detected a correct button press during the presentation of stimuli *ata 5* , *ata 6*, *ata 7* and *ata 8*.

2 The task employed in this experiment (and in the Experiment 4 involving infants as subjects) is considered to be a categorisation task since the subjects were told to respond to the change in the quantity category degree in the presented stimuli. The fact that the adults were told to respond when they perceived the *atta* word obviously means also that they had to identify it. But since the procedure involved repetition of the standard background word *ata*, to which the occasionally presented different stimuli from the continuum were compared, the task is considered to involve specifically discrimination between the two stimuli. Therefore, this task is occasionally referred to in the text as a discrimination task. The choice of this term is mainly due to the fact that when the task employed here and in Experiment 1 are compared, in order to distinguish the two categorisation tasks suitable terms were needed, which reflected the initial nature of the tasks. In Experiment 1, which is by nature a categorisation task also, the subjects' task was more specifically to identify the stimuli, and, therefore, that task is referred to as an identification task. It should be remembered though, that a categorisation task involves both discrimination and identification processing and that use of the terms discrimination and identification in the text does not mean that merely one of the processes is considered to be involved in the tasks.

3 The subjects were shown a piece of paper where the following was printed in capital letters: ATA ATA ATA ATA ATA ATA **ATTA ATTA ATTA ATTA** ATA ATA ATA. The location in the sequence where the first *atta* stimulus appeared was pointed to

instructions and the subjects were instructed to listen carefully due to this similarity.

In this experiment, two types of trials were used. The trial in which the background stimuli *ata1* changed to another stimuli from the continuum was the change trial. In addition, control trials in which there was no change in the stimuli were included in the paradigm. Evidence of positive categoristation in this procedure consisted of a button press on stimulus-change trials and the absences of a button press on control trials. In each 11 stimuli trial there was an observation period, which was measured from the beginning of the 5th stimulus to the beginning of the 9th stimulus (approximately 6 seconds). The responses during the observation interval were coded by the software programme as either hits, misses, false alarms or correct rejections according to the nature of each response (hits for button presses during the change trial, misses for no button presses during the change trial, false alarms for button presses during control trials and correct rejections for no button presses during control trials). An example of each trial sequence type is shown in Figure 10.

Observation period

Change Trial ata1 ata1 ata1 ata1/ ata8 ata8 ata8 ata8/ ata1 ata1 ata1

Control Trial ata1 ata1 ata1 ata1 /ata1 ata1 ata1 ata1/ ata1 ata1 ata1

FIGURE 10 Stimulus presentation during change and control trials. As shown, the standard background stimulus *ata1* occurred prior to and after each observation period in change trials, as well as all the time during control trials. During change trials, a random presentation of the stimulus from the stimuli continuum occurred. During the observation interval of control trials, stimuli from the background category were continuously presented. The observation period in the experiment with adults meant merely the response time window during which button press responses were coded on the software. In Experiment 4 with infant subjects the observation period meant the time during which the experimenter judged whether there was a head turn response or not.

The experimental paradigm involved three distinct phases: (1) the conditioning, (2) the criterion testing and (3) the categorisation phase. Throughout all three phases the speech stimuli were presented with a constant interstimulus interval of 1000 msec, thus eliminating any

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the subjects so as to illustrate also visually the point of the change which should be indicated by a press of a button.

potential temporal cue that might occur during the shift from background to target. The conditioning phase comprised only change trials. The background stimulus was *ata1,* as it was in all of the different phases of the experiment, and the target stimulus was the stimulus from the opposite end of the continuum, *ata8*. In addition, immediately prior to the experiment proper the subjects were presented with two preparation trials identical to the trials used in the conditioning phase in order to familiarise them with the task. These trials were not included in the analysis of the data. The criterion for proceeding in the experiment was three consecutive trials with a correct button press during the presentation of the target stimuli. During the criterion testing phase both change and control trials occurred. Again stimulus *ata8* acted as a target stimulus in this phase. The subjects were required to make correct responses in nine out of ten consecutive trials in order to proceed to the final stage of the experiment. In the categorisation phase, all 8 stimuli from the continuum occurred as targets on four different occasions. The computer software arranged the selection of target trials in a pseudo-randomised order. The stipulation for each trial type presentation was that all eight stimuli were presented once before they could be presented again in a different order (a randomised-block design). Also, no more than three trials from each category could be presented in a row. Altogether, the categorisation phase included 32 trials. The entire experiment took approximately 11 minutes to complete.

3.3.3 Results and discussion

Conditioning phase

The results of Experiment 3 demonstrate that all the adult subjects were able to discriminate the change from the background stimuli to the target stimuli in virtually every trial in the initial phases of conditioning. In the initial conditioning phase the criterion for proceeding into the next phase (three correct responses out of three successive trials) was met with the minimal possible score by all except two subjects (one from the dyslexia group and one from the control group who both proceed with the result of 3 out 4 trials correct).

In the following criterion testing phase the majority of the subjects proceeded with the minimum possible trials to the categorisation phase (9 out of 9 correct trials). Four adult dyslexic subjects (one female and three males) required 10 trials before proceeding to the next testing phase. The relationship between the results of these nominal data in the two subject groups was submitted to statistical analysis using a Chi-square test. The Chi-square frequency value revealed that there was no significant difference between the subject groups in responding to the target stimulus *ata8* (Pearson x^2 = 6.557, P = .05627[1]). There were four dyslexic adults who

1 P < ,05 * (almost significant difference)

contributed to the differences in the statistics. When their performances were investigated more closely, it appeared that two of them who indicated a change in the stimuli in a control trial had obviously accidentally pressed the response button since the reaction times[1] were around a few milliseconds (1 and 12 msecs). The performances of the two dyslexics who had missed the change of the stimuli in the change trial are not as easily explained. It is possible that they actually did not hear the difference between the stimuli *ata1* and *ata8.* However, factors such as attentional difficulties have to be taken into consideration in interpreting these results.

The response data were also investigated in terms of the reaction times to the ATTA-responses[2]. The reaction time data were used in order to gain further information on the speech perception processing. It is hypothesised that the more demanding the perceptual processing task is the more time it takes for the listeners to respond. In fact, the classically defined categorical perception phenomenon could be interpreted as meaning that since listeners should not perceive differences within categories then all the stimuli within the category should be responded to with the same speed (Massaro 1987, 276). However, several investigations over the years have demonstrated that this is not the case. For instance, the experiments of Pisoni & Tash (1974), Repp (1981) and Massaro (1987) have revealed increases in identification reaction times near the category boundary between two speech items. Massaro (1987, 278) concluded that the longer reaction times in the speech continuum indicate the ambiguousness of the those particular stimuli.

In the present experiment, since the button press responses involved only one button which was held in the subjects' hand, the motoric side of the response was not demanding (in comparison to employing several different buttons and if the response buttons could not be held in the hand), and was therefore considered to be constant across all the stimuli and the subjects. Another important factor to be considered in interpreting the reaction time data is that the accuracy of the responses may be sacrificed in order to respond fast. An attempt was made to minimise this factor by giving the same instruction to all the subjects to press the response button as soon as they heard the *atta* word. In addition, since the preceding conditioning phases provided opportunities for the subjects to practice the button press response, it is considered that the reaction time data in the categorisation phase is not influenced by the subjects initial unfamiliarity on the task.

P < ,01 ** (significant difference)

P < ,001 *** (highly significant difference)

1 The response time was measured only in the cases when the button was pressed for an indication of an *atta*-response. Thus, the data does not include information on reaction times in the cases for *ata*-responses.

2 Unfortunately, since the button press responses indicated the incidents in which the stimuli were categorised as *atta* but no indication of a response was required from the subjects when they categorised the stimuli as *ata*, the reaction time data, or more precisely the response time data, are only available for the *atta* categorisation responses.

The mean latencies of responses for the criterion testing phase were as follows: 866 msec in the dyslexia group and 794 msec in the control group. These latency times indicate that the responses were given on average already after hearing just the first item in the observation period. The reaction time data of the two subject groups were subjected to an analysis of variance test. The ANOVA revealed that there was no significant difference between the reaction times in the two subject groups in this practice phase.

In sum, the responses of the adult subjects showed that there is no difference between the dyslexic adults and the control adults in differentiating the VCCV stimuli with the long duration of the word medial consonant from that with the short duration of word medial consonant. This can be interpreted as meaning that the dyslexics do not have any problems in processing large durational differences in speech stimuli, and that they are able to utilise durational information in the categorisation of speech sounds. Previous research has also indicated that dyslexics do not have problems with temporal processing when large durational differences are involved (Brandt & Rosen 1980, Tallal 1980, Steffens et al. 1992). At the same time this result conflicts with the findings of Reed (1989) and Hari and Kiesilä (1996) whose results suggested that dyslexics may have problems also with processing large durational differences in auditory stimuli. The discrepancy between the results of Hari and Kiesilä and those of the present study could be explained by the fact that the nature of the tasks as well as the stimuli in the two studies were clearly different. The disagreement of the results between Reed's study and the present is not as easily explainable. However, the fact that the dyslexics in Reed's study did not have difficulties in temporal processing in TOJ tasks when the stimuli were vowels but only when the stimuli involved stop consonants and tones could mean that the shortness of the acoustic cues in the stimuli in TOJ tasks may have caused difficulties for the dyslexics in Reed's study.

Categorisation phase

The data from the categorisation phase were first analysed to compare the responses of the dyslexic adults to those of the control adults on the different stimuli from the stimuli continuum (eight stimuli presented in four separate trials). The results show that both subject groups categorised the stimuli with a changing duration of the word medial stop into two distinct categories: In general, the stimuli *ata1* and *ata2* were categorised as VCV structure words and the stimuli *ata5* to *ata8* were categorised as VCCV structure words. The stimulus *ata3* was categorised approximately half the time as either having a short or long quantity degree consonant. The stimulus *ata4* was categorised as having a long quantity consonant by most of the subjects but there were some responses indicating that the stimulus had a short quantity consonant. The categorical functions of the responses are presented in Figure 11.

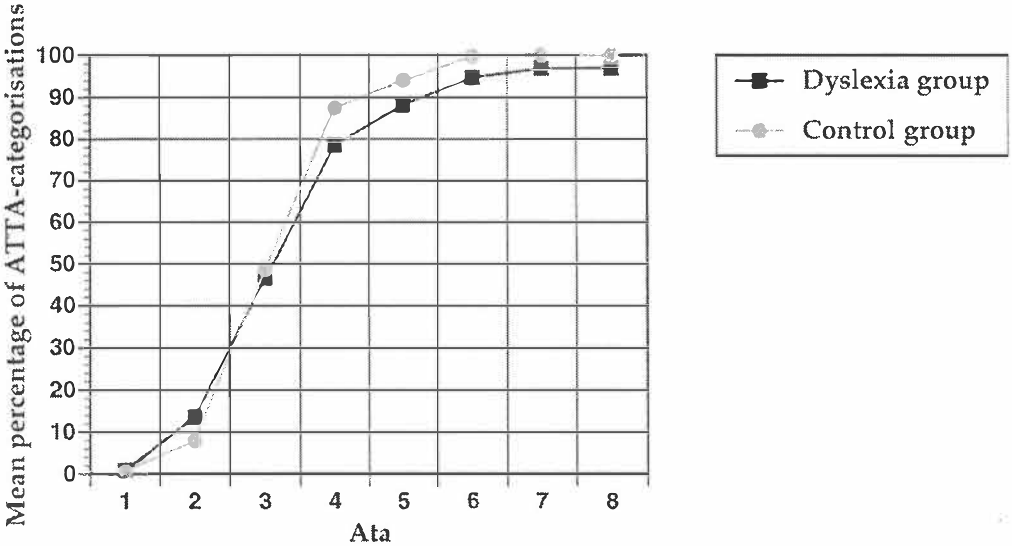

FIGURE 11 Categorisation function for the dyslexia group and the control group in Experiment 3. The 8 stimuli from the continuum are shown as numbers at the abscissa and the average percentages of the *Atta* responses are indicated on the ordinate. The functions of the two groups are similar in form but there is a statistically significant difference in the responses for the stimulus *ata*4 (Pearson x^2 = 7.699, P = .0055) in which the dyslexic adults gave *Atta*-responses significantly less often in comparison to the control adults.

The results indicated that there was almost a statistically significant difference between the groups in the responses on the stimulus *ata2*, the dyslexic adults identifying the stimulus as *atta* slightly more often than the control adults (Pearson x^2 = 4.569, P = .03255, tested using the Chi-square test). In the stimulus *ata4* the subject groups' responses differed more significantly. Considerably more often the control adult subjects categorised the stimuli as *atta* in comparison to the dyslexic adults (Pearson x^2 = 7.699, P = .00552). Also the responses to the stimulus *ata5* differentiated the two subject groups. Again the stimulus was categorised as *atta* more often by the control subjects than the dyslexic subjects but the difference reached only almost a statistically significant difference level (Pearson x^2 = 5.89897, P = .01515). The rest of the stimuli with the longer duration in the word medial consonant also differentiated the two subject groups in the same way (*Ata6*: Pearson x^2 = 13.30591, P = .00026; *Ata7*: Pearson x^2 = 9,45778, P = .00210 and *Ata8*: Pearson x^2 = 9.45778, P = .00210). Since the control adults' responses showed 100%[1] of *atta* responses in these stimuli, the small amount of *ata* responses in the dyslexic group made the difference statistically significant although the difference in numbers was not large. Thus, the difference at the subject group level between the categorisation function cannot be considered to be highly significant.

When the group data were investigated in terms of the location of the category boundary the data showed that the differences between the two subject groups were minimal. The control group adults located the boundary at approximately 136 msec and the dyslexics at 138 msec, and thus, statistically[2] this difference did not reach a significant level (ANOVA F 1.0377, P .3201).

In terms of the bandwidth[3] the results indicated group level differences between the two subjects groups. The bandwidth was longer in dyslexics in comparison to that in the controls, the bandwidths being approximately 71 and 48 msecs respectively. This difference indicates that there was a larger variability in the responses of the dyslexic adults in comparison to those of the control adults. In fact, statistical analysis (ANOVA) showed that the difference between the two groups was almost significant at the point at which 90 percent of the responses indicated *atta*-categorisations (F 5.0949, P .0257)[4]. When the data were analysed on the individual level it showed that the differences between the two subject groups were mainly due to certain individuals within the dyslexia group whose responses showed that they did not have steep category boundaries and had large phoneme boundary widths (see Fig. 12 as well as the individual data in Appendix 1). At the group level the difference in the bandwidths between the two subject groups was also statistically significant (ANOVA F 8.0231, P .0053). In other words, the performance of dyslexics indicated their uncertainty in this perception task. The results suggest that the edges of the categories were less distinct in the dyslexics indicating that the categories according to durational changes were not as distinctly represented in the dyslexic adults as in the control adults. In fact, several perception studies on dyslexia indicate that dyslexics are less consistent in categorising of speech sounds than nondyslexics (Brandt et al. 1980 , Godfrey et al. 1981, Werker et al. 1987, De Weirdt 1988).

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1 In responding to *ata6* there was one response out of 305 among the responses of the control subjects which indicated that the stimulus was perceived as a VCV structure word.

2 These statistics were calculated by first analysing the data from each individual separately after which the results were pooled together.

3 The bandwidth was defined as an area in which 80% of the changes between the categories occurred.

4 The statistical analysis (regression analysis) was conducted by first calculating three points in each categorical function of each individual: the point at which the curve reached 10%, 50% and 90 % of *atta*-responses. Then the data were divided into the two subject groups after which these were compared using ANOVA.

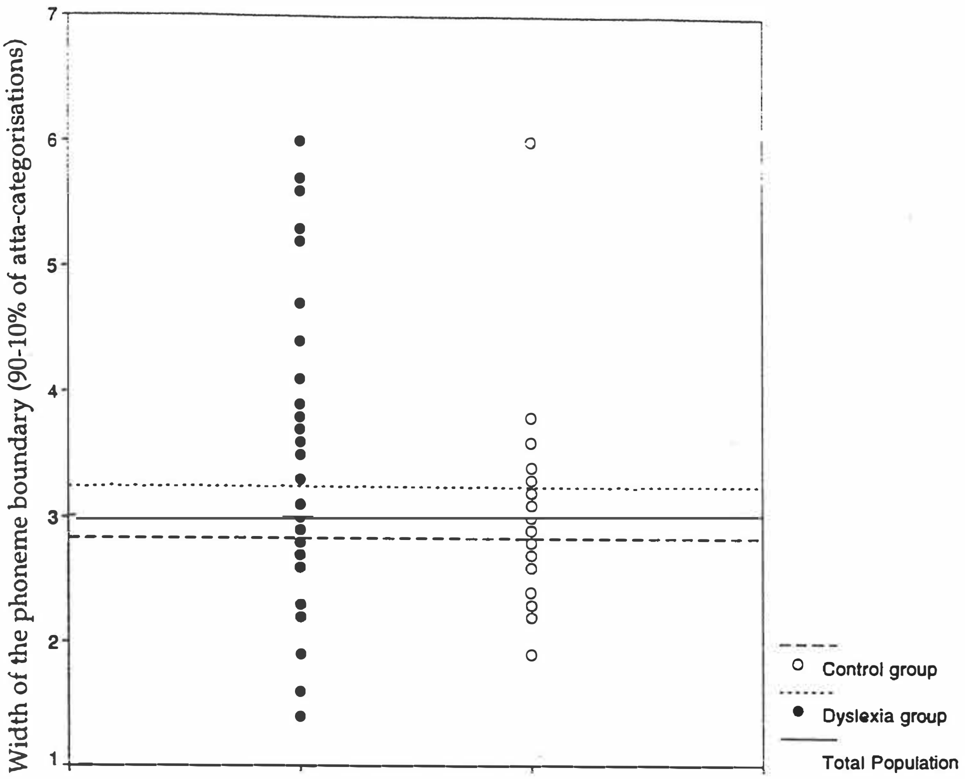

FIGURE 12 A graphical illustration of the widths of the phoneme boundary in the dyslexia group adults and in the control group adults. Means of each subject group as well as that of the total population are marked in the horizontal lines in the figure. This illustration shows that there is a larger variability in the responses of the dyslexic adults in comparison to those of the control adults.

The bandwidth was shorter here in the control adults as it was in the identification task of Experiment 1 employing the same stimuli. The category boundaries in this discrimination task and the identification task in Experiment 1 indicate that the boundary was almost in the same location between the two types of tasks, since in the identification task it was approximately at 140 msec and here at 136 msec in the control subjects. The difference in the boundaries could be explained by the different nature of the tasks employed in the two experiments. The presentation context as well as the frequency of the stimuli presentations can have a considerable significance in the results of the two different types of categorisation tasks involved here and in Experiment 1. In the present experiment the standard stimuli were presented in long series with relatively short interstimulus intervals. This can be considered to create a memory trace of the standard stimulus since the stimuli were repeated continuously during the 10 minutes of testing time. Also the stimulus *ata8* was repeated more often than the rest of the stimuli from the continuum and can be considered to have a role in creating a strong representation of the word with a long quantity degree. In Experiment 1 the subjects were required to respond to each stimulus after one presentation in a randomised context of other stimuli from the continuum. Therefore, the nature of the tasks differed considerably and this may have influenced the way in which the categorical functions differed in the two experiments. In addition, in Experiment 1 each stimulus was presented on 10 separate occasions to the 32 subjects but in the present experiment each stimulus was presented in the categorisation phase only four times to a larger number of subjects (57 in the dyslexia group and 76 in the control group). If each stimulus would have been presented the same amount of times in both of the experiments then the results would be more comparable. Now additional variables such as fatigue, practice, attentional aspects, changes in listening and responding strategies may have differently influenced the results in the two categorisation experiments.

The group data of Experiment 3 were also subjected to a signal detection analysis (*d′* score, Green & Swets 1966). This was done in order to discover whether the differences found in discrimination functions reflected the essentially perceptual abilities of the subjects or whether the responses merely reflect the biases of the subjects to respond in a certain way. The *d′* analysis takes into account response biases by calculating the probability of a correct response with respect to the rate of false positive responses. Figure 13 shows discrimination functions in terms of *d′* scores for the two subject groups. The *d′* scores[1] revealed that there was a statistically significant difference in the categorisation functions between the subject groups in responding to the stimulus *ata*6 (F 8.5202, P = .0041, tested with the ANOVA test) with the dyslexic adults' responses indicating less of a distinction between the standard stimulus *ata*1 and the stimulus *ata*6. Similar tendencies were revealed in responding to the stimuli *ata4*, *ata5* and *ata8*[2] but statistically the responses were almost significantly different (in *ata4*: F = 4.7836, P = .0305; *ata5*: F = 4.0695, P = .0457; *ata 8*: F = 5.7390, P = .0180). It appears that the dyslexic adults as a group did not distinguish the difference between the standard *ata1* and those stimuli with considerably longer closure durations as well as did the control adults.

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1 The *d′* scores were estimated by converting the experimentally obtained proportions to z-scores and subtracting the z score corresponding to false alarm responses from the z score corresponding to hit responses.

2 The responses to stimulus *ata7* fell just outside the level of statistical significance (F 3.5677 , P = .0611).

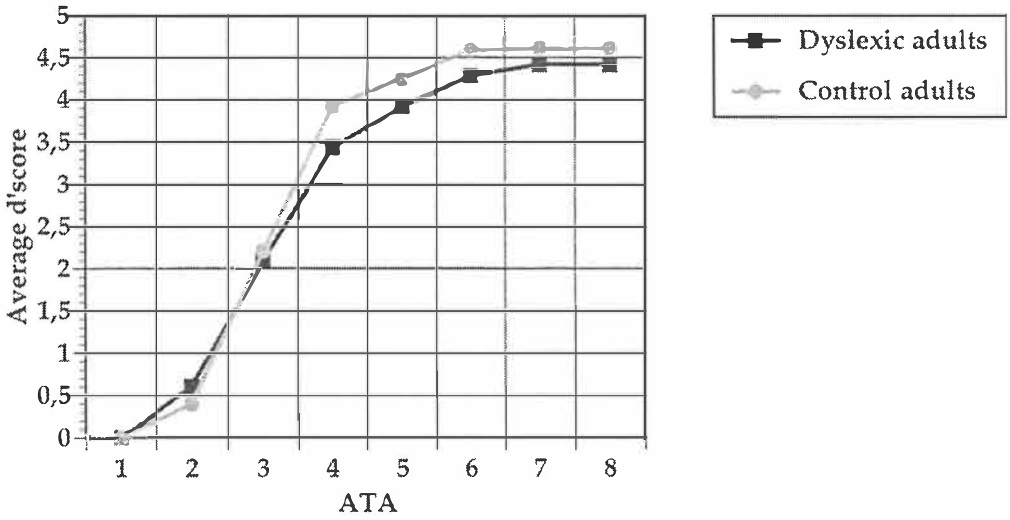

FIGURE 13 Discrimination data of Fig. 11 expressed in terms of *d'*scores. The 8 stimuli are showed as numbers in the abscissa and the group d'scores are shown in the ordinate. These function curves demonstrate similar tendencies to the function curves for the mean percentage of atta-responses. The dyslexic adults as a group categorise the stimuli from *ata4* to *ata8* less often as atta in comparison to the control adults.

The reaction time data were first analysed by pooling the data across the stimuli for both of the subject groups. The ANOVA showed that there was a highly significant difference between the two subject groups in the reaction times in as much as the dyslexic adults were slower in their *Atta*-responses than the control adults. Also the reaction times were investigated by analysing the data in terms of each stimulus. These reaction time data are graphically presented in Figure 14. The data show that in general the subjects gave an indication of an *atta* categorisation already after the first presentation of the stimulus in the observation period. The reaction times for positive *atta* identifications were given after two successive presentations of the stimulus in the stimuli *ata*2 and *ata*3[1]. Also in *ata*4, which is located near the category boundary, the responses were given on average after the explosion of the consonant in the second stimulus presentation. The reaction time data for each stimulus show that the latencies for responding were shortest towards the stimulus *ata8* which had the longest duration in the occlusion. In other words, the subjects were slowest responding to the stimulus in the middle of the continuum (*ata3, 4* and *5*). This result is seen as demonstrating that the less distinct the stimulus was perceived the longer it took for the subjects to give their *Atta*-

[1] The total duration of the *ata2* was 320 msec (the word initial vowel was 72 msec, the occlusion of the consonant 115 msec and the word final vowel 133 msec), and that of *ata3* 340 msec. For example, when the interstimulus interval was 1000 msec the reaction time data in the order of 2500 msec in responding to *ata2* stimulus means that the two presentations of the stimulus occurred before the responses.

responses. The statistically significant differences between the subject groups, using the analysis of variance test, were revealed in the following reaction times for the following stimuli: a highly significant difference in responses for stimulus *ata 8* (F = 11.1710, P = .0009), a significant difference in stimuli *ata5* and *ata7* (F = 7.6077, P = .006 and F = 6.2992, P = .0124, respectively) and almost a significant difference in *ata6* (F = 5.1771, P = .0233).

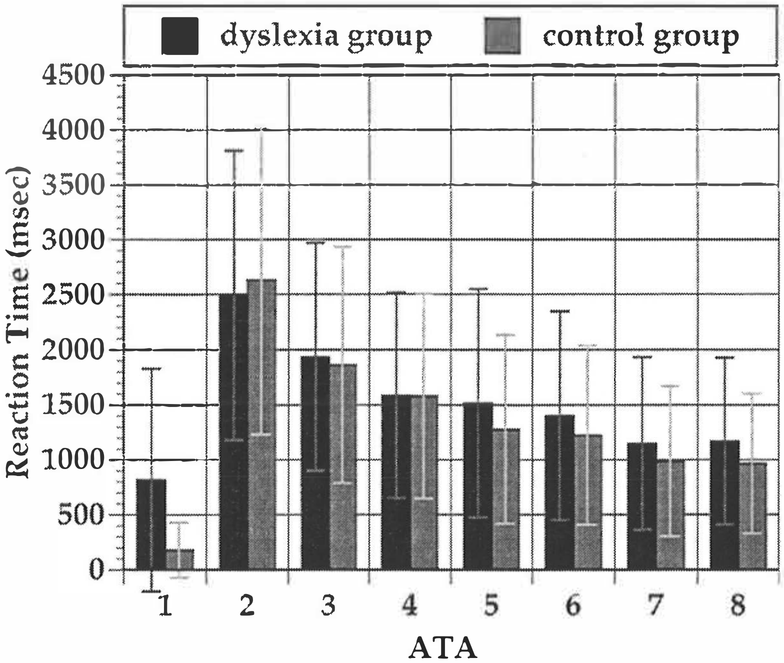

FIGURE 14 Reaction time data (means and standard deviations) for the two subject groups in Experiment 3. The stimuli are presented as numbers at the abscissa and the mean reaction times are shown in the ordinate. The bars demonstrate that the reactions were faster the closer to the stimulus *ata8*, the endpoint of the continuum, the stimuli were. Also the bars indicate that the control subjects were on average faster than the dyslexic adults in their responses. It should be noted that there were only 4 individuals who categorised stimuli *ata1* as *atta*.

An interesting fact about the reaction time data is the results in terms of the stimulus *ata8*. As it was pointed out earlier, there was no difference between the subject groups in the reaction times in responding to that particular stimulus in the earlier conditioning phases. In the categorisation phase the results revealed a highly significant difference between the groups, the dyslexic adults being considerably slower then the controls in their reactions to the stimulus *ata8*. This is interesting considering that the subjects had had practice responding to the stimulus *ata8* since it was also presented in the previous phases of the experiment. This detail may be an indication that the controls in comparison to the dyslexics, developed a more distinct representation of the two quantity degrees during the experiment context and thus were more certain in their responses making the judgement process easier and thus quicker. The fact that both of the subject groups responded after hearing just one stimulus in the observation period should be borne in mind. It is not clear if this statistical difference in reaction times has a comparable linguistic significance in normal communication situations.

The data from the two different subject groups were also analysed to compare the responses of the dyslexic adults to the different stimuli to those of the control adults when each stimulus was presented for the first time in the categorisation phase[1]. Grieser and Kuhl (1989) also performed this type of analysis of a first time presentations and considered the type of data important since they indicate the subjects' first reactions in categorising novel stimuli, without their having a representation or fixed points of reference in the immediate past to which the stimuli can be compared. Also the affect of the visual reinforcement (the mechanical toys) on the categorisation responses is thus eliminated, since in the first time trials the subjects had no knowledge on which responses to the reinforcement toys would be activated[2].

The results of the first time trials are presented in Figure 15. These results indicated the stimuli were categorised in a similar manner to that when each of them was presented all four times. The detailed results show that there was a statistically significant difference in responding to the stimulus *ata6*, caused by the control subjects categorising the stimuli as *atta* whereas some of the dyslexic adults categorised it as *ata* (Pearson x^2 = 8.37795, P = .00380). In addition, there was statistically almost a significant difference in responding to the stimuli *ata2*, caused by the dyslexic adults categorising the stimuli more often as *atta* in comparison to the control subjects (Pearson x^2 = 5.21569, P = .02238; Pearson x^2 = 4.36891, P = .03660, respectively). In the stimulus *ata5* there was also almost a statistically significant difference between the subject groups but this time the dyslexic subjects categorised the stimulus less often as *atta* in comparison to the control subjects. It should be noted that although there were no statistical differences between the two subject groups in the responses to stimuli *ata3* and *ata4* the results showed similar tendencies as those in which the differences reached a statistically significant level.

When the results for the dyslexics of the first time trials are compared to those of the total-time trials, it appears from the categorisation function curves that the differences between the two adult subject groups are even more significantly different in categorisations on the first exposure to novel category exemplars than in the total-time trials. This could indicate that the

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1 It should be noted that the stimuli *ata2* to *ata7* were actually novel in the categorisation phase but stimuli *ata1* and *ata8* had already been presented in the previous phases of the experiment. Nevertheless, all the eight stimuli included in the categorisation phase were subjected to the first-trial data including the *ata1* and *ata8*. Therefore, these two stimuli were not totally comparable to the rest of the stimuli in the first trial-data.

2 In fact, the subjects were not explicitly told the criteria which had to be met before the activation of the reinforcement toys would commence .

dyslexics need a larger amount of exposure to the different exemplars of the categorises in order to categorise the stimuli distinctly with varying durations of occlusions. Previous research has shown that perceptual boundaries sharpen with experience (e.g., Garnica 1973). Because the stimuli were pseudowords the subjects did not have a lexical representation of the words prior the testing. The task here required that each stimulus was compared to the background stimuli. This means that in order to be able to compare the stimuli the stimuli had to be stored in memory. Thus, some kind of representation of the stimuli had to be constructed during the testing. It could be that the results reflect that the time it took to complete the test was too short for the dyslexic adults to construct a stable representation of the stimuli. Or it could be that the dyslexic's memory or the strategy of using the stored representation of the stimuli was different than that of the control adults and thus they were not able to attend to the crucial features of the represented stimuli. The results are seen here as suggesting that dyslexics differ from nondyslexics in a representational level of the auditory stimuli.

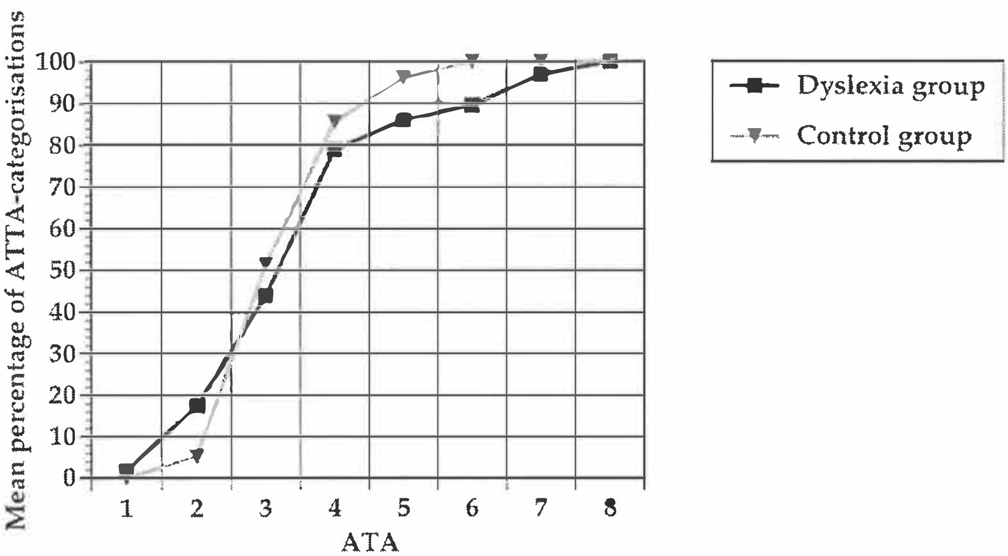

FIGURE 15 Categorisation function in the first time trials for the dyslexia group and the control group in Experiment 3. In general, the functions of the two groups are similar in form but there is a statistically significant difference in the responses to stimulus *ata6* (Pearson x^2 = 8.37795, P = .00380) in which the dyslexic adults gave significantly less often *Atta*-responses in comparison to the control adults.

Also the reaction time data of the first-time trials were analysed (see Fig. 16 for the graphical presentation of the results). In general, as in the total-time trials, the dyslexics were slower in their responses in comparison to the control subjects. When the reaction times of all the stimuli are pooled together there is almost a significant difference between the subject groups (F 4.6233, P = .0319).

The results of the individual stimuli showed similar tendencies as in the total-time trial data insofar as the reaction times became shorter the nearer the end point of the continuum the stimuli were located. These data indicated that statistically the differences between the subject groups reached significance only in the responses to the stimulus *ata8* (F 6.6570, P= .011). These results confirm the results of the total-time trials insofar as the difference between the subject groups is particularly significant in the end point stimulus in which the subjects had already had practice in the previous stages of the experiment. This can be interpreted as showing that the control subjects are quicker in getting a clear representation of the long quantity category in this experimental context.

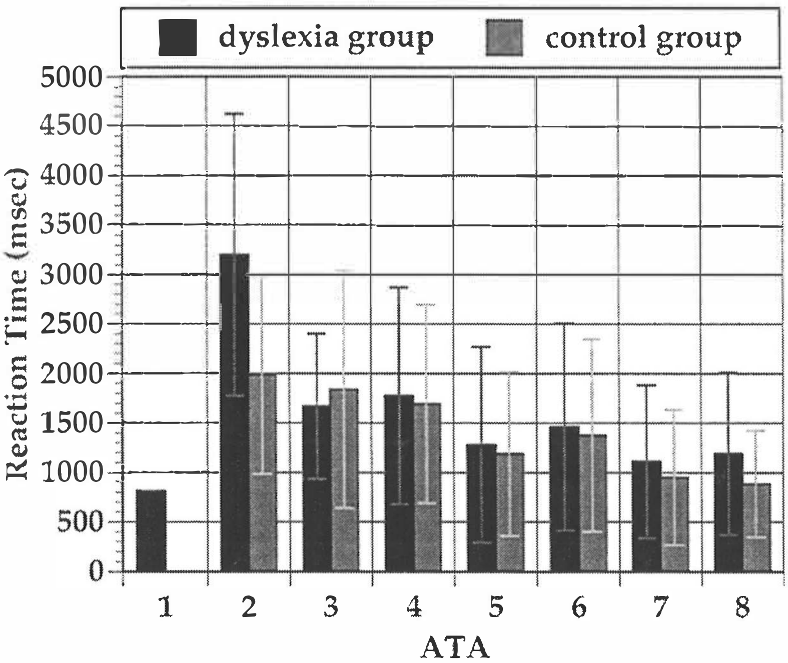

FIGURE 16 Reaction time data (means and reaction times) in the first time trials for the two adults subject groups in Experiment 3. There is a statistically significant difference in the responses for the stimulus *ata8*, with the control adults responding faster to the stimulus in comparison to the dyslexic adults (F 6.6570, P= .011).

Concerning the total-time trials, further analysis on the subject group level was done in terms of the gender of the subjects. In other words, in these analyses the subjects were divided into females and males within each of the subject groups. This was done in light of some experimental evidence (Debray-Ritzen 1987, Steffens et al. 1992) that there may be a difference in performance in terms of gender in dyslexics, males performing less like subjects with no dyslexia. The results according to the gender distribution in both subject groups are presented in Figures 17 (the dyslexics) and 18 (the controls).

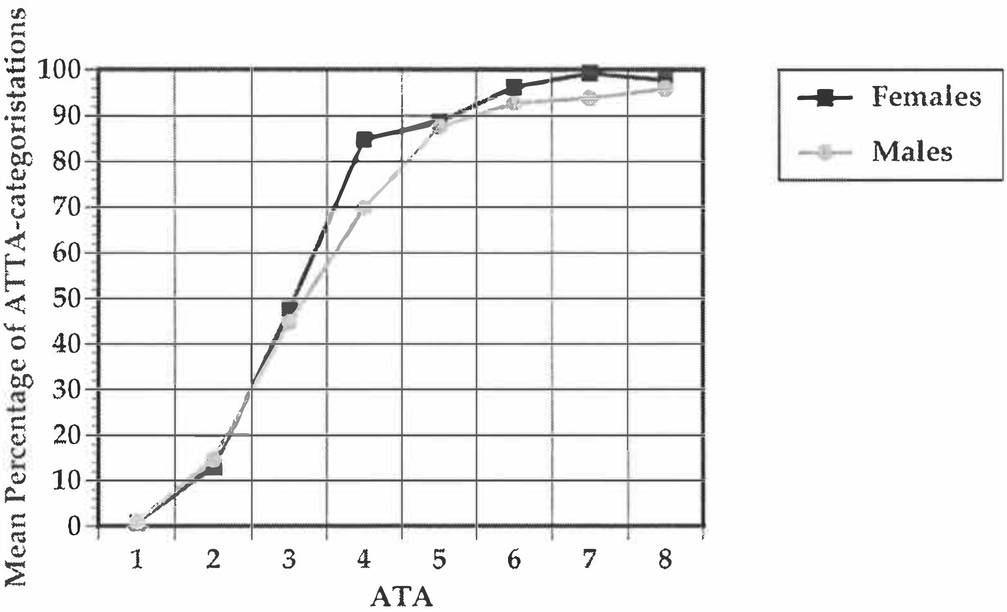

FIGURE 17 The categorisation functions for the females and males in the dyslexia group. The functions differ statistically significantly in stimulus *ata4* with the male dyslexics categorising the stimulus less frequently as *atta* in comparison to the female subjects. It should be noted that the gender groups sizes were different which may have influence these results.

In the dyslexia group there was a significant difference between the genders in categorising the stimulus *ata*4 (Pearson x^2 = , F 7,46788, P = ,00628) with the male dyslexics categorising the stimulus less frequently as *atta* in comparison to the female dyslexics. Similarly, there was also almost a significant difference in the responses to *ata*7 (Pearson x^2 = , F 5,63401, P = ,01762). Thus, it appears that the differences on the group level between the dyslexics and the controls were largely attributable to the dyslexic males in contrast to the dyslexic females. It should be remembered in interpreting these results that the group sizes according to the gender distribution were different, with 33 females and only 24 males. This factor may have contributed to the results. However, since there are indications that the performance of dyslexics males in comparison to females is even more strongly affected by the condition it could be that these results may reflect the difference in the genders. This assumption gains further weight by the results on a different genders in the control group (see Fig. 18). These results clearly demonstrate that the categorisation functions of the females and males were virtually identical in the control group. In contrast to the dyslexia group, there was not a considerable difference in the gender group size in the control group (40 females and 36 males). It seems that gender in general does not seem to affect the categorisation function here. However, there may be a tendency for dyslexics males to have more difficulties with temporal processing than females.

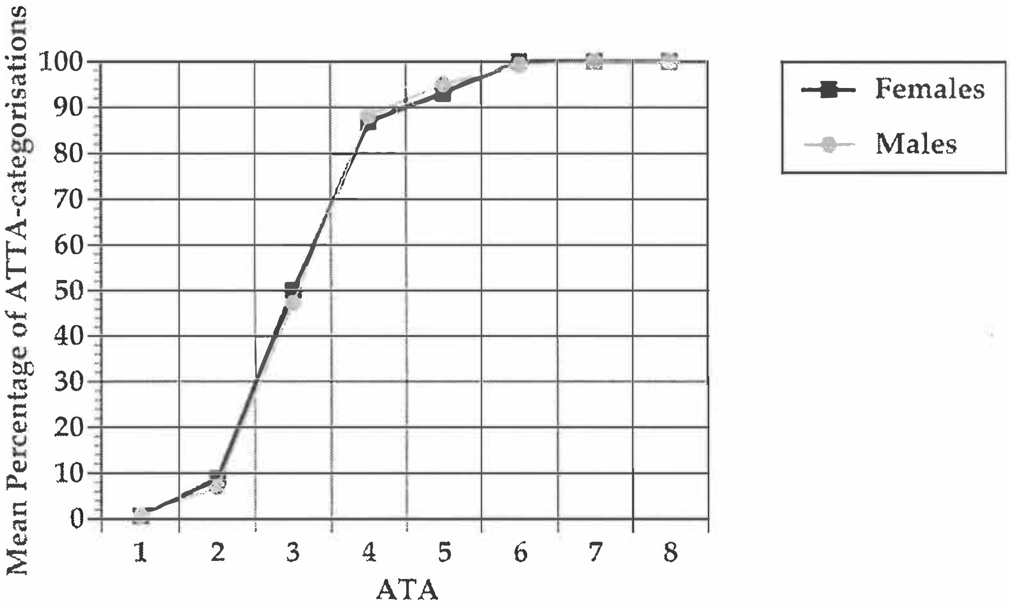

FIGURE 18 The categorisation functions for females and males in the control group. This figure illustrates that these functions are virtually the same between the control females and males.

The reaction time data (see Fig. 19) on the two genders revealed that in the dyslexic group there was no difference between the genders (on average, when the responses were pooled across all the stimuli, ANOVA F .0356, P = .8503). In the control group (see Fig. 20) there were differences in the reaction times between the two genders with the males being slower in their responses than the females. These results reached a statistically highly significant level in the control group (ANOVA F 12.5343 , P= .0004). When the control group results were investigated in more detail the only two stimuli in which reaction times reached a statistical difference level between the males and females were stimuli *ata2* and *ata4* (*ata2*: F 6.6820, P = .0169: *ata4*; F 4.0322 , P = .0457). Since there were only a few *atta*-responses from both genders in stimuli *ata2* in which the largest statistical difference was found it implies that on average the females were slightly faster than the males but this difference cannot be regarded as significant.

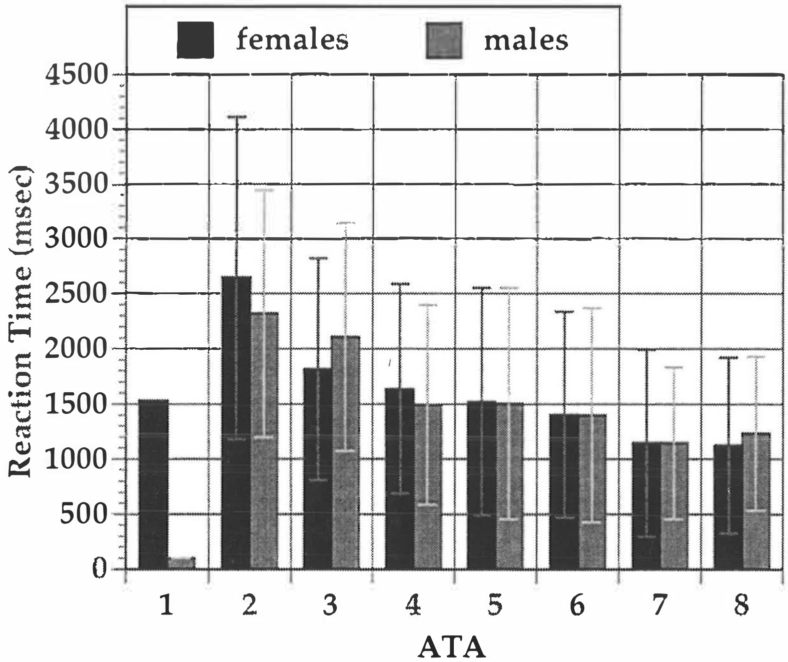

FIGURE 19 Reaction time data (means and standard deviations) in the dyslexic females and males. This graphical illustration shows that there is no difference in the data for females and males.

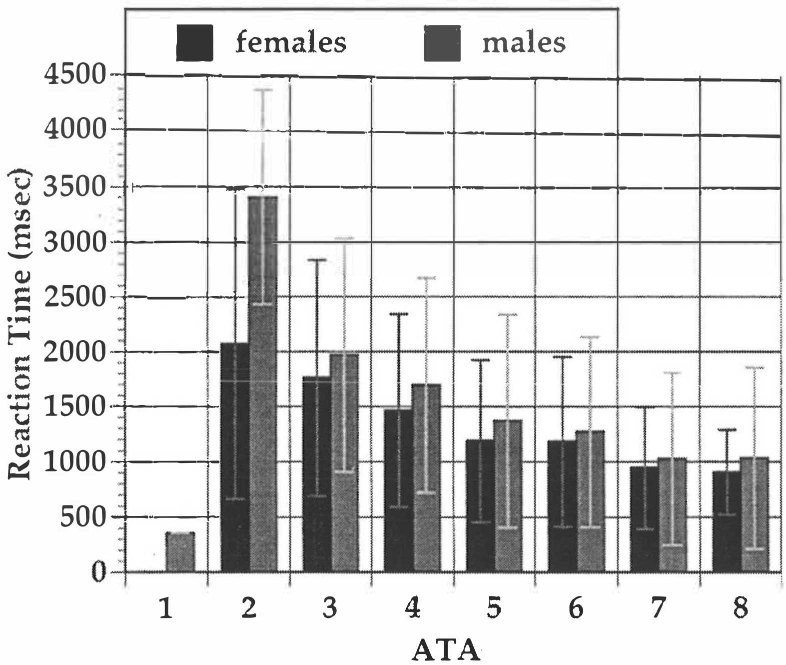

FIGURE 20 Reaction time data (means and standard deviations) in the control group's females and males. Statistically there is almost a significant difference in the reaction times in responding to *ata4* with the males being slower than the females.

Analyses of the data were also done on the individual level. More specifically, the dyslexia data were reanalysed in order to discover if the differences on the group level were due to the performances of some individuals rather than to a distribution of slight differences among all the dyslexic subjects. The specific concern was to investigate the responses to the stimulus *ata*4 which on the group level reached a significant difference level between the dyslexic and control adults. The results revealed that there were only three dyslexic adults (two males and one female) who never categorised the stimulus *ata*4 as a VCCV structure word. Interestingly, two of the individuals who never categorised the stimulus *ata4* as *atta* were the same individuals who had failed to recognise the stimulus *ata8* as *atta* in the practice phase of the experiment. They needed longer duration in the occlusion in order to categorise the stimulus as *atta*. Therefore, it may be that rather than attentional or other similar reasons being behind their lack of atta-responses in the practice phase, they did not actually consistently categorise the stimulus *ata8* as *atta.*

To return to the details of the results on the individuals in this categorisation phase, the results also showed that there were three individuals (all males) who categorised *ata4* once (out of four presentation times) as *atta*. In addition, there were five dyslexics (two females and three males) and two controls (a female and a male) who categorised the stimulus in question twice as *atta.* The rest of the *ata* responses were divided among a larger group of the dyslexics and the controls. It should be noted that the dialect of the adult subjects may have influenced the results to some extent. However, since the same stimuli were identified in Experiment 1 by a wide variety of speakers of various dialects in conformity, it is unlikely that dialect had any considerable impact on the results. The dyslexic individuals whose responses deviated most noticeably from the responses of the control subjects lived in the area of Jyväskylä. These results indicate that the difficulty observed in dyslexics as a group in categorise the stimulus *ata4* as the word *atta* is largely due to certain individuals. Furthermore, it seems that it is the male dyslexics in particular who seem to need a longer duration of occlusion in order to categorise it as a long quantity degree in the VCV structure word. Thus, these results are affirmative to those of Steffens et al. (1992) who also found that dyslexics and especially dyslexic males needed longer duration in order to shift their perception from one category to another. In general, the suggestion that dyslexics may have a temporal processing deficiency in perceiving shorter durations of sounds gained more support with these results. However, these results demonstrated that the proposed temporal deficiency does not apply to all dyslexics. It should be noted also that this experiment provides information only on temporal processing of speech sounds and, therefore, these results do not provide information on dyslexics' abilities to cope with other auditorily presented sounds. Thus it remain to be shown whether dyslexics have problems with mere auditory perception as Tallal (1980) proposes.

In sum, there were some differences in categorisation of the stimuli from the durational continuum between the dyslexic adults and the control adults. It seems that the dyslexic adults are less consistent as a group in the their categorical functions. However, a closer investigation of the results revealed that the group difference is mainly attributable to certain individual dyslexics. The results also demonstrated that dyslexic adults need a longer time to process phonetic information than nondyslexic adults. Therefore, it is suggested that representations are not as easily built in dyslexics and categories according to duration of sounds are not as distinct as they are in nondyslexic adults. The issues of representations and categorisations will be discussed later in Chapter 5 as well as in the results and discussion section of the infant experiment which will be described next.

3.4 Experiment 4

The results of Experiment 3 with the adult dyslexic subjects indicated that there may be a deficiency in some of the dyslexics in categorisation of speech sounds according to duration. In Experiment 4 an identical test to Experiment 3 was conducted with preverbal infants as subjects. These infants were the children of the adults participating in Experiment 3.

The categorisation skills of very young infants have been studied to some extent. Research on speech perception has provided evidence that children and even prelinguistic infants perceive some speech sounds categorically (see Eimas 1996 for review). Young infants' ability to categorise sounds according to duration has also been studied in some contexts. Most of the studies on speech perception have concentrated on studying the infants' ability to perceive differences in VOT[1] in a categorical fashion. The pioneering study of this kind by Eimas, Siqueland, Jusczyk and Vigorito (1971) investigated 1- and 4-month-olds' categorical discrimination of different VOTs in synthesised syllables /ba/ and /pa/. The investigators employed the high amplitude sucking (HAS) procedure[2] using several VOT pairs differing by 20 msec (the exact time difference which is employed as a variable in the present study). They found that both 1- and 4-month-olds from an English speaking environment were able to discriminate the VOT values which were from different categories according to adult data but that neither age group discriminated those VOT pairs located within a category. Eimas et al. (1971) concluded that infants could categorise stops according to their VOTs in a manner approximating categorical perception by adults. These results are supported by similar findings using VOT as a parameter in several studies from language environments utilising VOT in the voicing distinctions (e.g., Trehub & Rabinovitch 1972, Eimas 1975, Lasky, Syrdal-Lasky & Klein 1975, Streeter 1976, Eilers, Gavin & Wilson 1979a, Eilers, Wilson & Moore 1979b, Aslin, Pisoni, Hennessy & Perey 1981). Although these studies also showed some developmental differences between adults and young infants and influences of language experience as well as some universal trends, these results provide evidence that infants were able to utilise durational cues in the categorisation of speech sounds in some contexts at least.

However, as yet there exist no studies on the categorisation skills of 6-month olds according to duration in the quantity distinction. The objectives of Experiment 4 were to provide evidence on this aspect as well as to

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1 Voice onset time (VOT) refers to the timing differences in voicing contrast. VOT is usually defined as the duration between the release of a stop sound and the onset of voicing of the following vowel.

2 The HAS (high amplitude sucking) procedure was originally developed by Siqueland and Delucia (1969) to be used with very young infants since this technique employs a non-nutritive sucking response which even newborns are capable of producing. Typically, a spontaneous sucking behavior is utilised in the technique to implicate the reinforcing properties of novel stimulation (see Aslin, Pisoni & Jusczyk 1983, 581 for details on the procedure).

elucidate the ability in question in the infants with high genetic risk for dyslexia. The latter objective was interesting since there were some indications of the deficiency in the parents' of the infants studied here in the categorisation ability. The evidence provided by twin studies and some other studies concerned with genetics has indicated that there is a high risk of the infants of a dyslexic parent becoming dyslexics as well (Pennington 1990, Gilger et al. 1991a and 1991b, Stanovich 1994). Therefore, in the search for the possible early precursors of dyslexia the following research questions were addressed in Experiment 4.

3.4.1 Research questions

The aim of the study was to investigate if the ability of infants with high genetic risk for dyslexia to categorise sounds according to their duration deviates from the ability of infants with no such risk, thus indicating a possible early precursor for dyslexia. The results of Experiment 3 with adult subjects suggested that in a subgroup of dyslexics this ability is inferior to the controls. Also, since the quantity categorisation of young infants from the Finnish speaking environment has not previously been studied, the ability to categorise in terms of normal language development was under investigation here. The following questions were addressed:

1. Are 6 month old infants from the Finnish speaking environment able to categorise sounds which vary in the duration of a single sound according to duration?

2. If they are able to categorise does their categorisation function reflect that of the adult subjects in Experiment 3?

3. Is there a difference between the high genetic risk for dyslexia infants and the control infants in the quantity categorisation of the pseudoword *ata* with varying duration of the stop closure?

4. Is there a difference between the subject groups in the location of the category boundary in the durational continuum between the two quantity categories?

5. Is there a difference between girls and boys in the categorisation function?

6. Is there a difference between the two genders within the group of high genetic risk for dyslexia infants and within that of the control infants?

7. Is there a difference in the first-time trial data in terms of the different subject groups?

8. Are there differences in the categorical functions in relation to the first-time trial data?

3.4.2 Method

3.4.2.1 Subjects

A total of 176 infants ranging in age from 5.5. to 7.1 months participated in Experiment 4. All the infants were healthy full-term infants with presumably normal hearing[1]. Eighty-seven of the infants (46 GR+ infants and 41 GR- infants) failed to show any reliable evidence of acquiring the head-turn response and were excluded from the study. Altogether 89 six-month old (age range = 5.24 to 7.6 months, M = 6.5) infants completed the test in Experiment 4. Forty-three of the subjects (14 females and 29 males) belonged to the high genetic risk for dyslexia group (GR+) and 46 (22 females and 24 males) belonged to the control group (GR-), who did not possess this risk. Screening criteria for inclusion in the GR+ sample were identified as dyslexia of a parent and reported reading problems of the infant's siblings or other relatives. The parental assessment included a spelling test, two tests of reading aloud, a computer assisted FON-ORTHO system and the Raven Progressive Matrices Test (>85) (see the section *Subjects* on pages 86-92 for more details). The attrition rate of 49% in this experiment is similar to those of previous experiments using complex stimuli with young infants (e.g., Aslin et al. 1981)[2].

3.4.2.2 Stimuli and apparatus

The stimuli were identical to those used in Experiment 3 (see 92-93). The infants were tested in a small sound-attenuated room, while seated on a parent's lap. To the left of the infants at eye level two boxes were situated

1 Also, all the infants had uneventful pre- and perinatal circumstances and birthweights above 2,500 grams. The data of the infants whose parents reported recent or ongoing occurrences of otitis media were not included in the analyses in the present study.

2 It should be noted that subject loss during infant psychoacoustic procedures is relatively high. However, some infant researchers employing the head-turn paradigm have reported comparatively smaller attrition rates: rates as low as 5 to 20% (Kuhl 1979) have been reported for easily descriminable vowel stimuli and rates as high as 75% for more difficult consonant contrasts (Aslin et al. 1983 referred to Katz & Jusczyk' study from 1980). Thus, the smaller attrition rates are most likely contributed to by the fact that the stimuli used in those experiments are relatively easy (less complex) for instance using single vowels etc.

including visual reinforcement toys (see Picture 1). The purpose of the visual reinforcement was to maintain the infants' interest in the task for long periods of time. Furthermore, the use as well as the type of visual reinforcement have been shown to have a significant impact on infants performance (Moore et al. 1977, Trehub, Schneider & Bull 1981). These mechanical toys could not be seen through the shaded windows of the boxes until they were illuminated when the computer software initiated the movement of the toys[1]. A high quality loudspeaker (Yamaha monitor speaker M S 101) from which the stimuli were presented was situated on the top of the boxes. An assistant[2] was seated to the right of the infant and the parent. The assistant manipulated small toys[3] to attract the infant's gaze from the side from which the reinforcement toys were located during the testing procedure. This was done in order to prevent the infants from facing the reinforcement toys continuously. The testing was started by the assistant[4] and she could also interrupt the testing if necessary (if the infant was wiggling or otherwise moving excessively, had hiccups, needed to have a nappy changed, cried, was clearly frightened of the reinforcer toys, was sleepy, was hungry, was not paying attention to the task by being preoccupied either with the parent, or the assistant, or the silent toys, or the reinforcement toys, or the apparatus, etc.)[5]. Also the experimenter was able to give instructions to the assistant via the headphones and the microphone. The assistant wore headphones (Beyer Dynamic DT 209) with a microphone attached to them. The parent also wore headphones (Pioneer SE-30A 8Ω) through which music[6] was played at a comfortable listening

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1 The two mechanical toys, a drumming bunny and a drumming bear, were animated by the computer in a random order. Either one or both of the toys could be animated. The unpredictable presentation order of the reinforcement toys was included in the experimental design in an attempt to keep the infants motivated for the whole period of testing.

2 Mainly because of the long lasting data collection span, various persons acted as assistants in the experiment in some individual cases. However, in the majority of the cases which were included in the results it was me who acted as the assistant.

3 The assistant tried to move the toys silently thus not disturbing the perception of the stimuli and at the same time to manipulate them in a relatively uninterstingly manner so that the infant would fail to pay attention to the task at hand.

4 The assistant used a footswitch in order to start and stop the testing.

5 The task of the assistant was highly demanding. The assistant had to be continuously sensitive to the child's arousal state, attention and sedation. She had to observe the infant continuously to ensure that there was nothing preventing the performance of the infants in the task. To facilitate the task the assistant observed the infants prior to the testing in order to get a sense of the "personality" of the infant (whether the infants were shy, sociable, startled easily, etc.). Also the assistant had to ensure that the parents felt comfortable in the experimental situation by giving instructions and guidelines on what was likely to happen. This was considered important since the uneasiness of the parents can easily be reflected in the behavior of the infants.

6 The following music was played during the experiment: Vivaldi: The Four Seasons, Flute Concerto in C" II Gardinello and Mozart: Eine Kleine Nachtmusik, Piano Concerto no 23 in A major. The selected music was considered relatively neutral in

level. The purpose of the music was to mask the presented stimuli from the adults so that their reactions to the stimuli would not influence the performance of the infants. The insulation of the headphones was tested so that the infant would not hear the music but could concentrate on listening to the stimuli. Also the assistant heard music from the headphones when not communicating with the experimenter. The music was played through a high quality cassette recorder (Philips AV audio-visual portable stereo cassette recorder). The experimenter communicated with the assistant with the aid of the microphone and an amplifier (Tascam Multi headphones amplifier MH-40). The experimental procedure was controlled online by the computer (Amiga Commodore 2000) in the adjoining control room. The experimenter viewed the infant on a TV-monitor (20") during the entire testing procedure and coded the infant's head-turn responses with the press of a button, which was interfaced to the computer when a red light on top of the TV-monitor was lit indicating an observation period. The entire experiment was videotaped with a high quality videocamera (JVC Super VHS videomovie GR-S505, Hi-Fi stereo) and recorded with a video recorder (Sony DA Pro 4 head/high speed rewind/high quality picture/ data screen SLV 353).

3.4.2.3 Procedure

The assessment of the categorisation abilities of the infant subjects was made using a conditioned head-turn procedure. The technique used here was a modified version of that of Kuhl and her colleagues (e.g., Kuhl 1985a, Kuhl, Williams, Lacerda, Stevens & Lindblom 1992.). The head-turn procedure is based on infants' instinct to turn toward a new sound source. In the procedure used here the aim was to condition infants to turn their heads towards the loudspeaker whenever they perceived a change in the quantity category within an auditory sequence. Correct head turns were visually reinforced. (Some of the details of the procedure are described in the *Procedure* section of Experiment 3 on pages 94-96).

The procedure involved three consecutive experimental phases as well as two practice phases. Initially 30 background stimuli (*ata1*) were presented in order to familiarise the infants with the sounds and the experimental situation. The stimuli were presented with a constant 1000 msec interstimulus interval. The stimuli were played at a comfortable listening level, at approximately 70 dB.

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rhythmicity to prevent any rhythmic movements of the parents from influencing the reactions of the infants.

PICTURE 1 Picture taken in the test situation. An infant sat on his parent's lap. An assistant was seated on the right hand side. At an angle of 90° to the left of the infant and at eye level two boxes were situated. The windows of the boxes were shaded in order to conceal the bunny and the bear, which were lit when the toys started to drum. The loudspeaker from which the stimuli were presented was situated on the top of the boxes. The video camera was placed at a 135° angle in front and to the left of the infant. The researcher and the parent both wore headphones and heard music while the infant was tested.

In the second practice phase the infants were presented with 8 change trials (see the type of trials in Fig. 10, page 95). The stimulus *ata8* served as a target stimuli. In order to facilitate the orienting response towards the sound change the target stimuli were presented at a 10 dB higher level than the background stimuli during the first 4 trials. In the subsequent practice trials, the intensity of the target was reduced in two 3-dB steps until the target and background were equated at 70 dB. The presentations of the target stimuli were automatically accompanied with the visual reinforcement[1], i.e., the mechanical toys moved.

In the first experimental phase, the same background and target stimuli were presented. This time all the stimuli were presented at the same sound level (70 dB) and the system was calibrated regularly using a Brüel and Kjaer precision sound-level meter (Type 2235). In this phase only correct headturn responses were reinforced. A headturn response was recorded by the experimenter if the infants turned at least approximately 30° toward the loudspeaker during the observation period (the observation period for scoring the infants' head-turn response began with the onset of the first target stimulus and ended 1 sec after the fourth target repetition making a total response interval of approximately 6 secs see Fig. 10). The computer program kept a running tally of the infants' correct responses and when a predetermined criterion of 3 consecutive correct head turn responses was met the conditioning phase was terminated and the criteria testing phase was initiated.

In the criteria testing phase the same stimuli (*ata1* and *ata8*) were used as in the previous phases. This time, control trials were also introduced. These were added to measure if there was spontaneous turning in the direction of the loudspeaker during the experiment. The computer software presented the trials in a pseudorandom order with the stipulation that only three trials of one type could occur consecutively. Throughout the experiment the experimenter and the assistant were naive as to the type of trial presented. If a head-turn button was pressed on a control trial, the computer did not present the visual reinforcer. The proceeding criterion in this phase was 6 out of 8 correct responses (hits and correct rejections).

The categorisation phase began immediately after the previous phase. In this phase all the stimuli from the continuum were presented in four trials (a total of 32 trials). The order of the trials was randomised with the constraint that all the stimuli were presented once before they could be presented again, and that only three trials with stimuli from one of the categories could be presented in a row. Only headturn responses in the trials with stimuli *ata5* to *ata8* were reinforced. In both the criterion testing phase and categorisation phase, probe trials were also included. These "wake-up" trials occurred whenever the infants failed to respond correctly on three consecutive trials. These trials comprised three change trials in which the first target stimuli were presented 7 dB louder than the background stimuli,

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1 The presentation of the visual reinforcers was timed so that they were shown immediately after the second target stimulus was presented. In this way the infant also had a chance to respond to the change in stimuli prior the reinforcement.

and the second 4 dB louder, and the third at the same intensity level as the background stimuli. These same trials were also utilised if the testing was reinitiated[1] after it had been interrupted for a longer period of time. Neither the probe trials or the refresh trials were accounted for in the final data.

The whole experiment took 11 minutes to complete, without interruptions and with the subject reaching the criteria for conditioning (initially 3 consecutive correct head turns when stimulus number 8 was presented, eventually 6 out 8 correct responses) with the lowest possible number of stimuli presentations. On average, the test took the young infants 25 minutes to complete (the time ranging from 17 to 40 minutes).

All the data were rescored from the video tapes for head turns by a second judge. The interscorer agreement was extremely high as assessed by correlations. The correlation between the original and reliability scorings for trials averaged .98 across the means ranging from .95 to .99. Also the experimenter who had scored the headturns online and reported after the test that she had forgotten to press the button once during the test or that she had pressed the response button accidentally, pointed out these incorrect cases from the data. These incidences constituted approximately 2% of all the responses.

3.4.3 Results and discussion

Conditioning phases

The data from the conditioning phases of Experiment 4 were analysed in order to see how many trials the six-month-old infants needed in order to be conditioned to turn their heads towards the *ata8* stimulus which had substantially long duration of the stop closure in comparison to the standard stimulus *ata1*. The results demonstrated that the majority of the infants were able to consistently discriminate the difference between the stimuli *ata1* and *ata8*. In fact, 83 percent of all the infants met the criterion for proceeding on to the practice phase (three correct headturns out of three successive trials) with the minimum possible score. The rest of the infants proceeded in the experiment with the following scores: four infants after four trials, five after five trials, two after two trials, three after seven trials, and one after ten trials. According to ANOVA there was no statistical difference between the two subject groups in the performance in this initial conditioning phase (F .3213, P= .5723; the mean amount of trials was 3,5 in the GR+ group and 3,4 in the GR- group). Neither was there a difference between the two genders in this respect (ANOVA, F 3.3016, P= .0727). In general, the results reveal that the infants as young as 6 months old can discriminate the difference in the speech sounds according to duration.

1 These trials were used to refresh the task in the infant.

In the practice phase the mean average score for proceeding in the experiment was 12, (the scores ranged between 9 to 29) for all the infants (the lowest possible score according to the proceeding criterion was 6). There was no statistically significant difference between the two subject groups in this phase of the experiment. Neither was there a difference between girl and boy infants in responding to the stimuli. The mean reaction times were approximately 2568 msec in GR+ group and 2654 msec in GR- group. The mean reaction times were not statistically different either between the subject groups or the two genders.

In the practice phase so called wake-up trials were also utilised in cases where the infants failed to turn their heads on three consecutive change trials. The mean of the wake-up trials was of the order of ,2 and ,3 in the GR+ and GR- groups respectively. The results on these data showed that the amount of wake-up trials between the subject groups as well as the two gender groups was relatively even. The amount of wake-up trials, as well as the attained scores for preceding in the experiment indicate that these young infants were able to perform in an adult-like fashion when the stimuli were as distinct as they were here. For reasons of possible fatigue or inattentiveness or for other similar reasons the scores were lower in the practice phase in comparison to those of adults in Experiment 3. All in all, the results of the conditioning phases show that the six-month-old infants from the Finnish speaking environment were able to categorise the two stimuli with considerably different word medial consonant durations. In addition, the categorisation abilities did not differ between GR+ and GR- infants or between girls and boys. Thus, there is not deviancy in the risk infants in the basic categorisation abilities. This means that there cannot be any cross differences between the high genetic risk for dyslexia infants and those with no such risk in the processing of large durational changes within speech sounds.

Categorisation phase

The data on the categorisation phase were first analysed in order to discover whether six-month-old infants were able to categorise stimuli with several durational variations of a single sound. In order to do so, the data of the control infants were investigated. The total-trial time data showed that there were similar tendencies to the adult data in the categorisation function: the stimuli from the shorter end of the durational continuum were perceived as distinct from the stimuli from the longer end of the continuum. The difference between the adult and infant data is in the degree of distinctiveness in the two categories, the adult results revealing clearly more distinct differences between the two quantity categories (see Fig. 21). However, the steepness of the category functions between the infant and adult data is relatively similar. It appears that the main categorisation function shows similar tendencies in six-month old infants to that of adults. The reasons for the less steep categories of the infant data can probably be attributed to some intervening factors such as inattentiveness and fatigue during the testing. Obviously the results may also demonstrate that these young infants do not categorise the stimuli with variable sound duration into two distinct categories as consistently and systematically as adults.

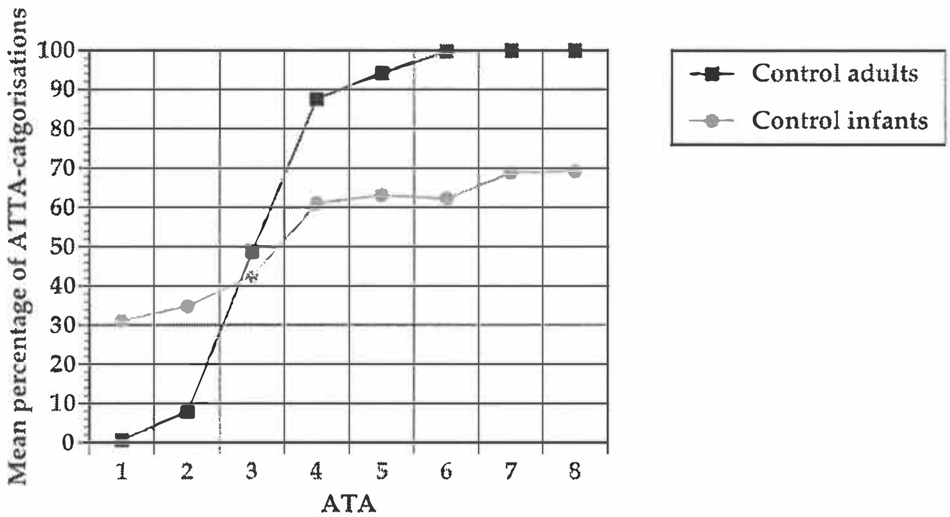

FIGURE 21 The categorisation functions of the control adults and control infants. The curves are clearly different but the directional tendencies are similar between the adult and infant data.

The possible categorical nature of the infant speech perception with durational parameters gains additional support from the fact that these results showed a distinct place in the continuum which divided the responses into two categories. In addition, the locations of the category boundary between infants and adults were very close to each other: The category boundary in the control infant data was located at approximately 142 msec whereas that of the adult data was at 136 msec. Similar tendencies have been demonstrated earlier in categorisation studies using another durational parameter, VOT. For example, Kuijpers (1993, 98) studied categorisation abilities of Dutch children and adults and discovered that the category boundary was more elevated in young children than in old children and adults. It therefore seems that there is a developmental trend in the location of the category boundary according to durational parameters. The question whether this category boundary is learned or whether it is based on some natural durational boundary cannot be solved with the present experiment. In order to do so experiments with infants with different language backgrounds would have to be conducted. Most likely the category boundary revealed here is located in a natural auditory psychophysical area but there may be other similar areas in a durational continuum which speakers of other languages utilise in categorising sounds.

It should be noted that the tasks in the adult and infant data are not directly comparable. The reason for this is that in the instructions already the categorical nature of the task was pointed out to the adults. The task of the young infants was more like a discrimination task on the basis of which the categorical assumptions can be inferred.

The infant data were analysed next in terms of the possible differences between the high genetic risk for dyslexia infants and those with no such risk. The total-time trial data in percentages of atta-categorisations are graphically illustrated in Fig. 22. These results indicate that both subject groups' responses show similar categorical tendencies. However, the results differ remarkably in one respect. The control infants categorised the stimulus *ata*4 more often as *atta* in comparison to the risk infants. In fact, the difference between the two groups in this respect reached a highly significant difference when tested with a chi-square test (Pearson x^2 = 23.32418, P = .0000). There were statistically significant differences in the responses to the other stimuli: the stimulus *ata1* was perceived less often as *atta* by GR+ infants, (Pearson x^2 = 7.58245, P = .00589), and the stimulus *ata5* was perceived by the GR- infants more often as *atta* (Pearson x^2 = 8.45933, P = .00363). In addition, the difference in responding to stimulus *ata*7 reached almost a significant difference level with the GR- infants categorising the stimulus more often as *atta* in comparison to the GR+ infants (Pearson x^2 = 3.75102, P = .05278).

In terms of the category boundary the data revealed that it was located approximately at 142 msec in the GR- infants and around 180 msec in the GR+ infants. This means that the GR+ infant's categorisations were significantly further away from the adult categorisations. Furthermore, the degree of steepness in the category function indicates that the GR+ infants had less distinctive durational categories in comparison to the GR- infants and the adults. The results are strongly suggestive that reason for the less sharp categories is a perceptual temporal deficiency of the GR+ infants. The temporal processing ability has been shown to improve with age (Eilers, Bull, Oller & Lewis 1984, Morrongiello & Trehub 1987, Elfenbein, Small & Davis 1993) which entails that these GR+ infants may be developmentally behind the GR- infants. It is possible that they would catch up with the GR- infants later on in the development. Further research is needed in order to elucidate this possibility. Although developmental catching up seems feasible it is highly unlikely that all of the GR+ infants would do so. Therefore, the interpretation is favoured here according to which dyslexia may be connected to a permanent temporal processing deficiency.

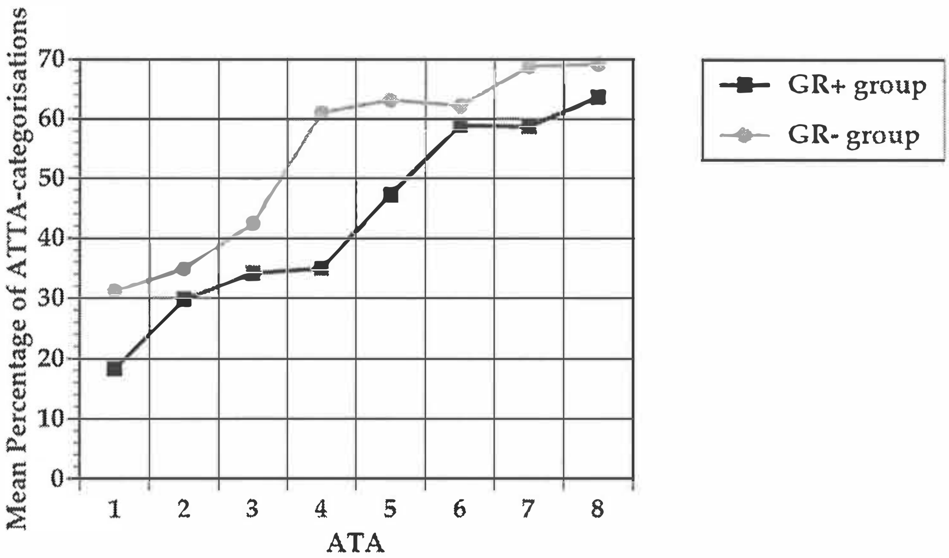

FIGURE 22 The mean percentage of Atta-categorisations in the high genetic risk for dyslexia infants (GR+) and those with no such risk (GR-). There is a highly significant difference in the responses between the two subject groups to the stimulus *ata*4 (Pearson x^2 = 23.32418, P = .0000) with the GR+ infants categorising the stimulus more often as *atta*.

In order to discover whether the observed group differences were caused by differences in the response biases of the subject groups, the *d'*score analyses were also conducted on the infant data. The data were analysed for statistical significance by t-tests for independent samples. The t-tests for equality of means indicated that there was no statistical difference between the responses of the subject groups in the responses to any of the stimuli between the two subject groups. The *d'*score curves show (Fig. 23) that the difference in the categorisation functions according to the response percentages cannot be due to the fact that the GR- infants were more inclined to turn their heads during the observational period than the GR+ infants. In conclusion, it appears that the infants with high risk for dyslexia needed remarkably longer duration in order to categorise the stimuli as *atta* in comparison to the control infants. These are similar tendencies as in the adult group data in Experiment 3. Also previous research has shown similar trends in adult' dyslexic data (Steffens et al. 1992). Also previous research has shown evidence that dyslexics may have a perceptual temporal processing deficit specifically with brief acoustic signals (e.g., Tallal 1980, McCroskey & Kidder 1980, Watson 1992). It also appears that the GR+ infants have less distinct representations of the categories according to the durational features of speech.

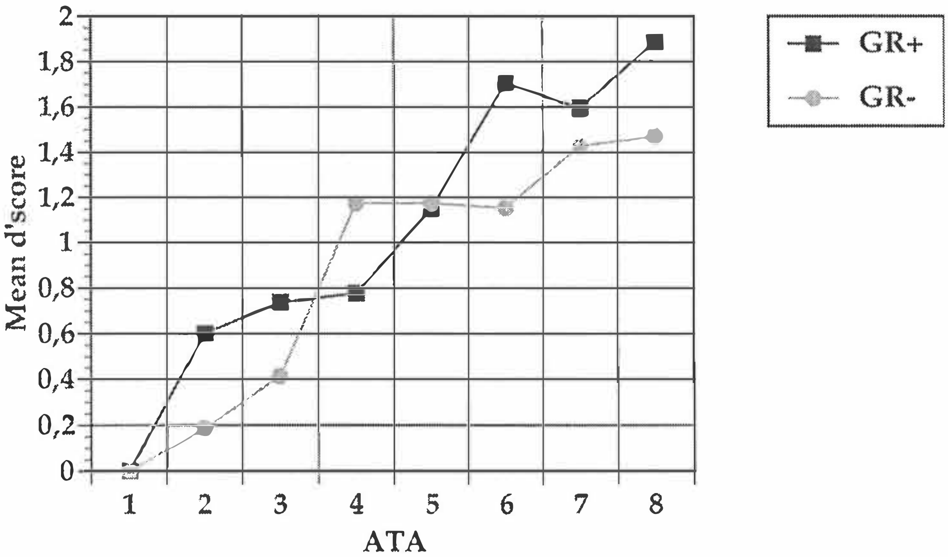

FIGURE 23 The discrimination data of Fig. 22 expressed in terms of *d'*scores. The 8 stimuli are shown as numbers in the abscissa and the group d'scores are shown in the ordinate. The *d'*scores of the two subject groups show that in terms of the statistical differences in the percentage data the difference in responding to *ata4*, *ata5*, *ata7* and *ata2* is not due to the fact that GR- infants were more inclined to turn their heads without a change in the stimuli.

The head-turn data were also analysed by investigating the reaction times of the head turn responses in the two subject groups. It should be remembered, though, that this measure is not as objective as it was in the adult data since here the times were recorded from the point at which the experimenter pressed the response button in identifying the head-turns of the infants. The average reaction times pooled across the stimuli revealed that both of the subject groups indicated a change in the category after two stimuli presentations in the observation period. This result means that the infants were remarkably slower in their responses than the adults. This feature of the results could be expected on the basis of previous research in reaction times with different age subject groups. Young infants and children are slower in their reactions than older children and adults. Here the slowness can partly be explained in terms of the motoric abilities related to head turns which are not very advanced in six-month-old infants. In addition, it cannot be ruled out that the reaction times of the scorerers and their decisional strategies may have influenced these results taking account the fact that the task of the online scorerer was not always simple since the head turns of the infants were not always obvious. The reaction time data pooled across the stimuli revealed that there was a slight difference between the subject groups with the GR- infants being faster in their responses than the GR+ infants (ANOVA F 4.5143 P= .0338). This result shows similar tendencies to those found in the adult data in which the dyslexic adults were slower in their responses than the control adults.

When the reaction times were investigated in more detail, no significant differences in the reactions times between the two subject groups with each stimulus were seen in the data. A graphical illustration of the reaction time data is presented in Fig. 24. This infant data also clearly indicates that unlike in the adult data there was not a clear tendency for the reaction times to reflect the location of the stimulus in the continuum. Since the nature of this data and the developing motoric skills of the infants both affected the results as was pointed out earlier, speculations regarding the impact of these results are not valid here.

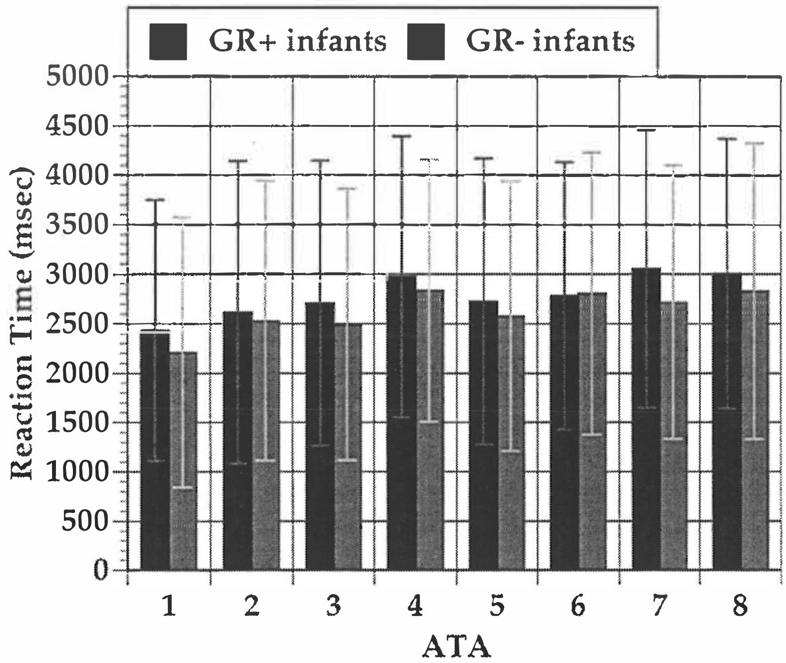

FIGURE 24 Reaction times (means and standard deviations) for the head-turns in the GR+ and GR- infant data. There is no clear tendency in the results as to the effect of the stimulus in the reaction times.

The first-time trial data for the infants were also analysed. This is particularly important in an infant experiment like the present since reinforcement was provided for certain responses but not for others. Thus, in an attempt to prevent the visual reinforcement from influencing the results, the first-time trial data were studied in the two subject groups. These data are also presented graphically in Fig. 25.

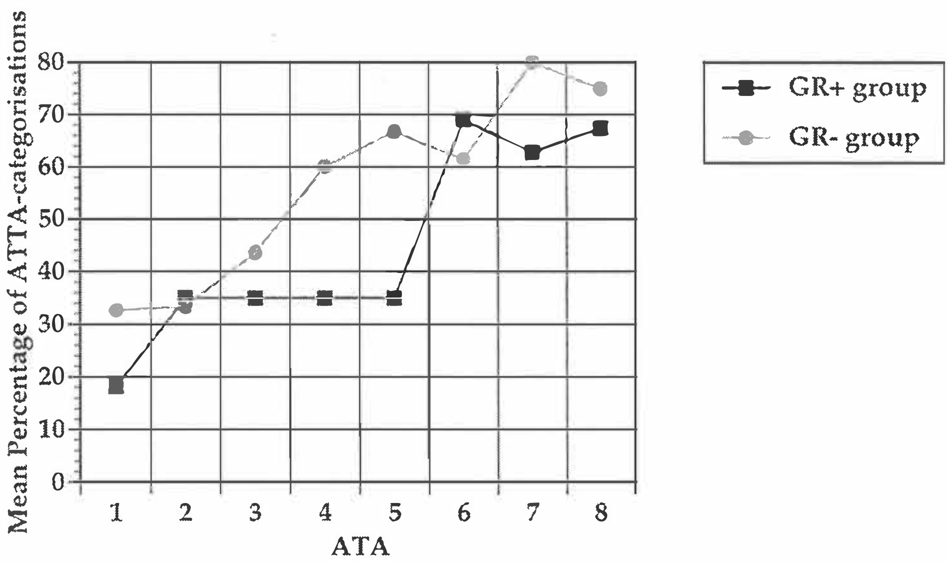

FIGURE 25 The first-time trial data in Experiment 4 with 6 month old infants as subjects. The results revealed that there was a significant difference in the performance of the two subject groups with the control infants (GR-) indicating more *atta*-responses in comparison to the high genetic risk for dyslexia infants in the stimulus *ata4* and *ata5*.

The first-time trial data emphasised the tendencies found in the total-time trial data. The data showed that the infants perceptually divided the stimuli into two categories already at the first exposure to the novel exemplars of the durational continuum. This may be seen as an indication that the categorisation according to a durational continuum cannot be merely learned since the stimuli were pseudowords but is based on to some natural psychophysical categorical boundaries dividing short and long sounds. The differences between the two subject groups were similar to those in the total-time trials. Statistically significant differences were found between the two subject groups in the responses to stimulus *ata*4 and *ata*5 (Pearson x^2 = 5.55990, P = .01838 and Pearson x^2 = 8.88937 , P = .00287, respectively). The category boundary was located approximately at 143 msec in the GR- group and 183 msec in the GR+ group. These results match those of the total-time trial data. Thus, the differences revealed in the two subject groups' performances in the total-time trial data and the first-time trial data are cognate. The control infants' responses in comparison to the infants' with the high genetic risk for dyslexia are more like the adult responses. These results strongly suggest that the risk infants have a temporal processing deficiency in dealing with the durational differences of speech stimuli. They seemed to need longer sound duration in order to shift from one durational category to another. This could mean that they cannot discriminate the small temporal differences of speech sounds as well as the control infants; or that their representations of categories are not consistent for some reason; or that the risk infants need to be exposed more to the speech stimuli with variable durations in order to form more stable categories. Or all of these suggested explanations may lie behind the difference found in this experiment.

In an attempt to ensure that the differences found in the two subject groups so far are related to the dyslexia risk factor, the infant data were analysed using different grouping of the subjects. This time the data were grouped according to the gender of the infants. The female group comprised 36 girl infants and the male group 53 boy infants. The total-time trial data according to the two genders are illustrated in Fig 26.

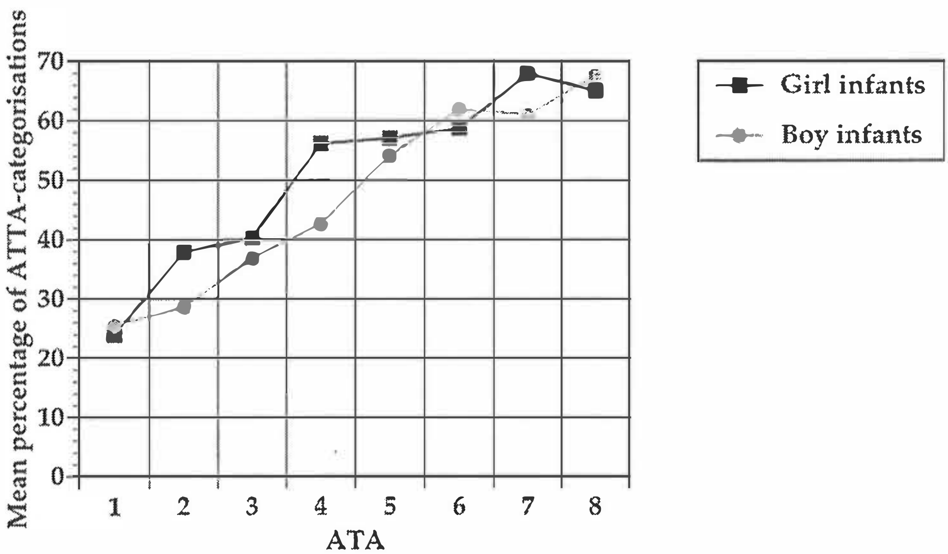

FIGURE 26 The mean percentage of ATTA-categorisations in the girl infant group and in that of the boy infants. There is a significant difference in the categorisation of the *ata4* stimulus, with the girls indicating more *atta*-responses than the boys. It should be noted that the two gender groups here are made up of subjects from both the GR+ and GR- groups.

The chi-square test revealed that there was a significant difference in the responses to the stimulus *ata4*, with the boys indicating atta-responses relatively less often than the girls (Pearson $x^2 = 6.04777$, P = .01392). No other statistically significant differences were found between the girls and boys. The *d'*score analysis of the gender data did not reveal any significant difference in the performances of the two subject groups either. Does this result suggest that in the responses to stimulus *ata*4 that the larger differences found between the GR+ and GR- group infants is not due to the dyslexia factor but something else? It should be noted that the single difference found in the gender groups is significantly smaller than the one found in the GR+ and GR- groups. More importantly, the difference in the group sizes between the two genders may have contributed to the outcome of the results here in the gender grouping[1]. However, in order to investigate this matter further, the gender data were analysed next in terms of the first-time trials.

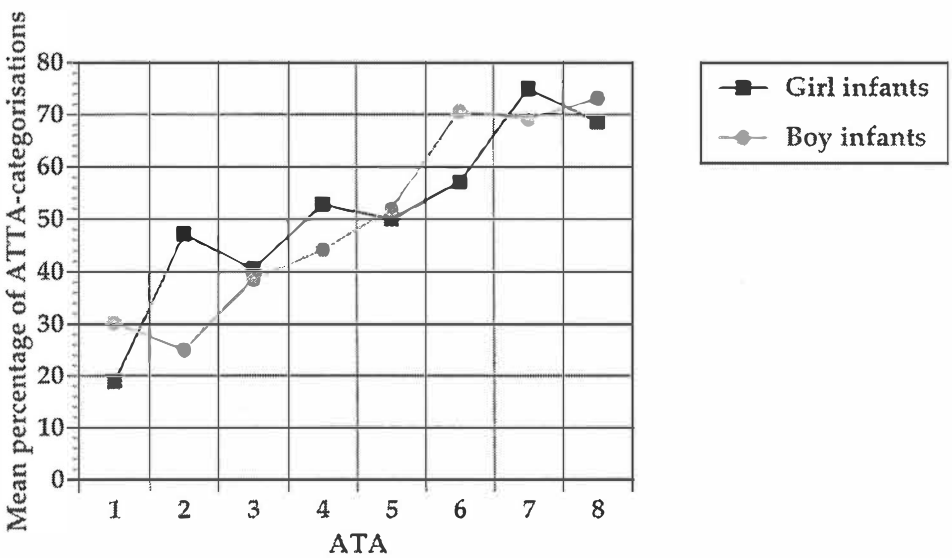

FIGURE 27 The mean percentage of ATTA-categorisations in the first-time trial data between the girl infant group and that of the boy infants. There is a significant difference in the categorisation of the *ata4* stimulus, with the girls indicating more *atta*-responses than the boys. It should be noted that the two gender groups here are made up of subjects from both the GR+ and GR- groups.

The first-time trial data are graphically presented in Fig 27. The statistical analyses of these data revealed in an almost significant difference between the responses of the gender groups only one of the stimuli: the results indicated more atta-responses in the girl infants when the stimulus *ata2* was presented (Pearson x^2 = 4.67535, P = .03060). Although the differences in the responses did not reach statistical significance in the other stimuli, the data were revealing. In the graphical illustration of the data as can be seen in Fig. 27, the amount of the head turns in the girl infants was relatively high regardless of the stimuli. Only during the presentations of the stimuli *ata7* and *ata8* were there clearly more head turns than in the rest of the stimuli. The boy infants, on the other hand, turned their heads less frequently along the stimuli continuum except in the stimuli *ata6, ata7* and *ata8* during which more of the boy infants responded with a head turn. The general tendency in the girls to turn their heads more frequently than the

1 In the GR+ and GR- groups the difference in the size of the groups was considerably smaller with 43 GR+ infants and 46 GR- infants.

boys is not easily explained. In addition, the fact that the head turn responses during the stimulus *ata*4, which appears to have a crucial role within the continuum, were not reinforced, discounts the explanation according to which the group differences were caused by the effect of the reinforcement. However, the reinforcement toys may have been more appealing to these girl infants, since they did seem to turn their heads more frequently than the boys. Or it may be that the more exposure to the stimuli (in contrast to the first-time trials) made the girl infants shift their category boundary to the stimulus with the shorter duration of the word medial consonant, whereas the amount of exposure in this test was not adequate for same effect to perform with the boy infants. In any case, it should be remembered that the differences in the results of the GR+ and GR- groups were considerably greater than those in the gender groups. Furthermore, the first-time trial data were in accordance with the total-time trial data in the results of the GR+ and GR- groups whereas those in the two gender groups were not. In conclusion, since the only statistical differences found in the results of the two gender groups were not highly significant or consistent these differences are not considered to be significant.

Since there was a slight difference in the responses of the two genders, additional analyses were executed according to the genders. First, the infant data were analysed dividing the two gender groups further in the GR+ and GR- groups. The data of the girl infants in the GR+ and GR- groups are presented in Fig. 28. The results of the total-time trial data demonstrated that there were significant differences in the performances of the two girl groups: a highly significant difference was found in the responses to the stimulus *ata4* (Pearson x^2 = 13.19657, P = .00028), a significant difference in the *ata5* (Pearson x^2 = 8.77242 , P = .00306) and *ata7* (Pearson x^2 = 9.68145 , P = .00186), and almost a significant difference in *ata1* (Pearson x^2 = 4.41036 , P = .03572). In terms of the first-time trial data there was a statistically significant difference in responding to the stimulus *ata5* (Pearson x^2 = 7.48052 , P = .00624) with less of the GR+ girls turning their heads (see Fig. 29). Interestingly, the curves of the categorisation functions demonstrate that the GR+ girls did not differentiate sharply between the two categories in the middle of the continuum, whereas the categorisation function curve of the GR- girls indicates similar distinct tendencies to those of the adults. An important fact should be noted about the number of infants: since there were substantially less GR+ girls in comparison to the GR- girls these aforementioned percentile differences appear to be large also in numbers. In sum, these results show similar tendencies to the whole group data with respect to the GR+ and GR- groups. Therefore, it appears that the differences between the girl and boy data were mainly due to the differences in the data of the GR- infants.

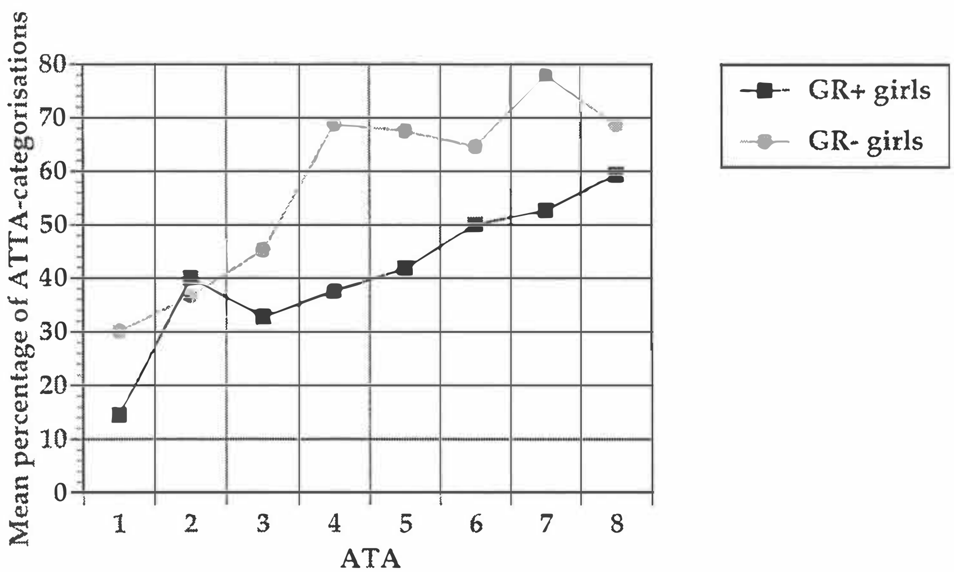

FIGURE 28 The categorical functions for the girl infants in the GR+ group and the GR- group. These functions demonstrate that the responses of the girl infants in the two subject groups differed significantly.

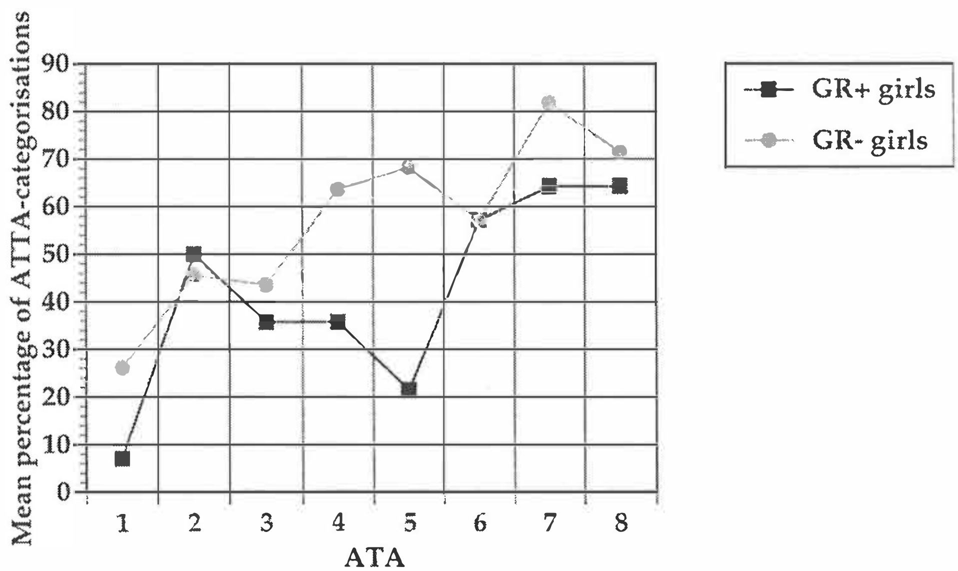

FIGURE 29 The categorical functions in the first-time trial data for the girl infants in the GR+ and GR- group. These curves indicate that the girl infants in the GR+ group needed longer duration to make *atta*-responses consistently.

The data of the boy infants are graphically presented in Figs. 30 and 31. The total-time trial data showed that there was a statistically significant difference in responding to stimulus *ata4* with the GR+ turning their heads less frequently in comparison to the GR- boys (Pearson x^2 = 8.39533, P = .00376). Also the difference found in the responses to the stimulus *ata1* reached almost a significant difference level (Pearson x^2 = 3.84302, P = .04995), the GR- boys giving *atta*-responses more often this time. In the first-time trial data the differences did not quite reach the statistically significant level. However, when the curves of the categorisation functions are investigated the tendencies of the differences are in accordance with the results gained so far concerning the differences in the GR+ and GR- groups. Interestingly, the GR+ boys' categorical functions are steep across the category boundary indicating a distinct categorical representation of the stimuli. This is clearly different in comparison to the GR+ girl infants who appear to have significantly less distinct category boundaries. In conclusion regarding the gender divisions between the GR+ and GR- group data, it can be said that the responses of the high genetic risk for dyslexia infants differ remarkably from those of infants with no such risk specifically in the area of the category boundary: the GR+ infants both boys and girls need longer duration to make *atta*-responses consistently.

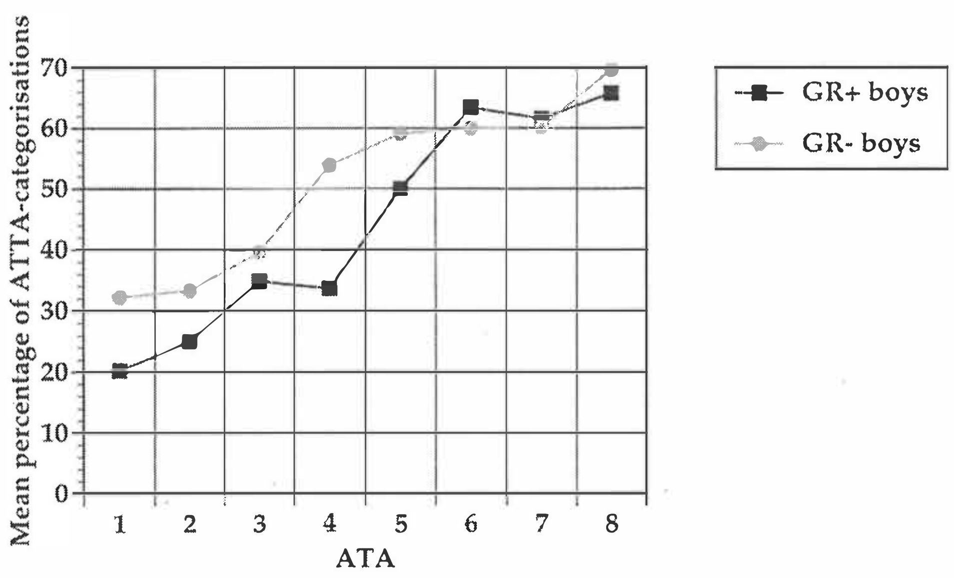

FIGURE 30 The categorical functions for the boy infants divided according to the GR+ and GR- groups. Statistically these functions differed in *ata*4 (Pearson x^2 = 8.39533, P = .00376), in which the GR+ boys indicated less *atta*-responses in comparison to the GR- boys.

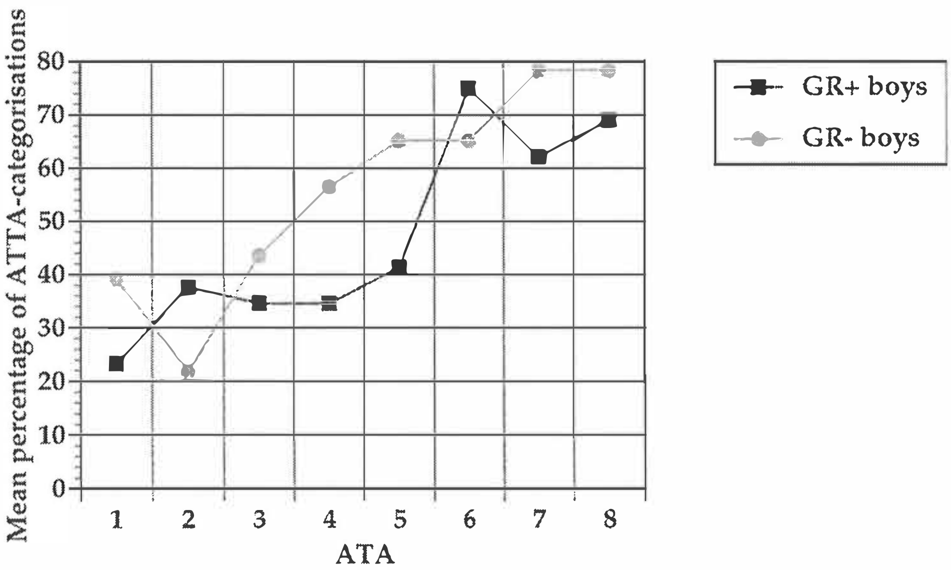

FIGURE 31 The first-time trial data of the boy infants in Experiment 4 with the boy infants divided into GR+ and GR- groups. The curves indicate that the GR+ boys need longer duration for *atta*-categorisations in comparison to GR- boys. Although the functions seem to differ considerably statistically these differences are not quite significant.

Final analyses according to gender were executed within the GR+ and GR- groups. First the results of the GR+ group are presented. The data of the girl and boy infants in the GR+ group are graphically presented in Figs. 32 and 33. The total-time trial data revealed that there are no differences between the two genders except in responding to the stimulus *ata2*, in which there was almost a significant difference, with the girl infants giving more indications of *atta*-responses (Pearson x^2 = 4.01096, P = .04521). Similar tendencies were apparent in the first-time trial data in which no significant differences were found. Importantly, the responses to the stimulus *ata4*, which stimulus at this stage can be seen to have a crucial role in the results, were virtually identical between the two gender groups. In conclusion, there did not appear to be any crucial differences between the two genders within the high genetic risk for dyslexia group infants. Therefore, these results do not suggest that there would be differences in terms of gender in the possible language deficiency with respect to genetically transmitted dyslexia. Thus, these results do not support in themselves previous observations of the more evident dyslexia in boys in comparison to girls. However, it should be remembered that these results should be treated as preliminary in terms of dyslexia since we do not yet know how many of these infants will eventually become dyslexics. Therefore, the results according to the two genders (deviations) like all the other results will have to be re-examined after these infants have passed the initial stages of formal reading instruction.

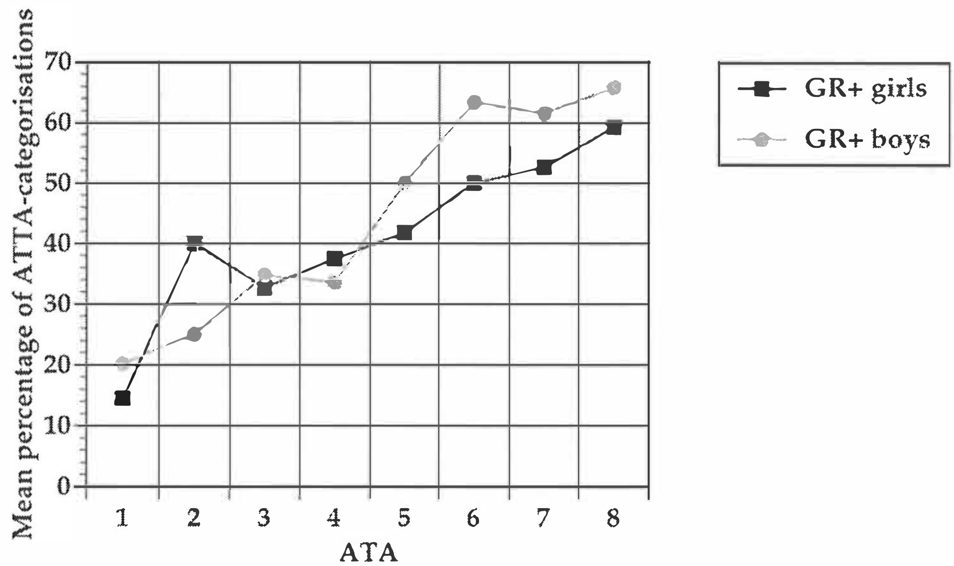

FIGURE 32 The total-time trial data for the girl and boy infants in the GR+ group. There are no significant difference between these functions.

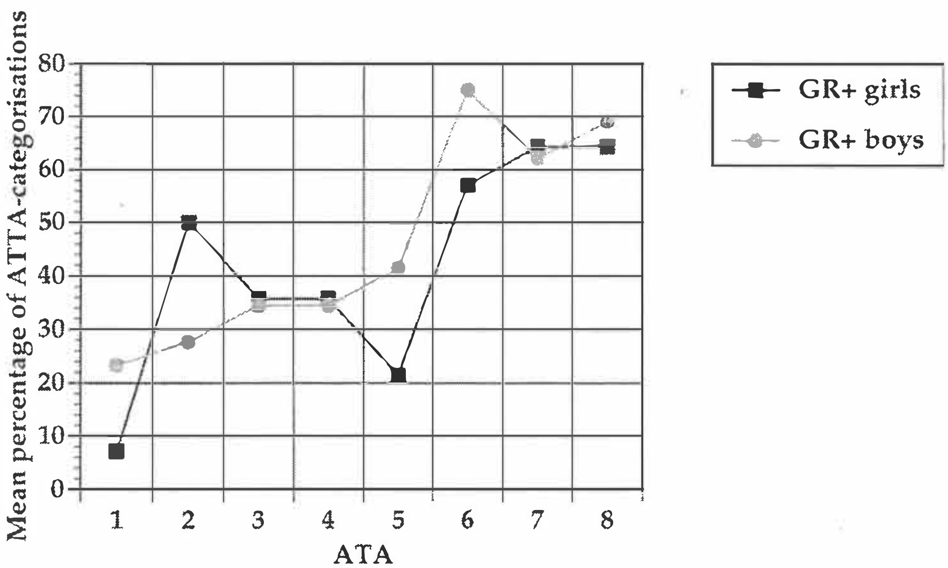

FIGURE 33 The first-time trial data for the girl and boy infants in the GR+ group. Again there are no significant difference between these two groups.

The GR- groups infants were also investigated in terms of gender. The results are presented graphically in Figures 34 and 35. The total-time trial data between the girl and boy infants revealed a significant difference in responding to the stimulus *ata7* (Pearson x^2 = 6,28308, P = .01219) and also almost a significant difference in the stimulus *ata4* (Pearson x^2 = 3,92511, P = .04757). Since the group sizes were almost even, with 22 girl infants and 24 boy infants, the differences cannot be explained by the group sizes. Several tentative explanations could be given. Perhaps these girl infants were more attentive in the task. Or they may have been able to sustain longer their interest in the reinforcement toys in comparison to the boy infants in the control group. As these suggestions show there is no really obvious explanation for the results. Interestingly, similar differences between the girl and boy infants in the control group were not apparent in the first-time trial data (see Fig. 35). Also it should be noted that the data between the two genders in the control group were clearly closer to each other than those in the GR+ group. Therefore, it appears that the differences found here may not be significant.

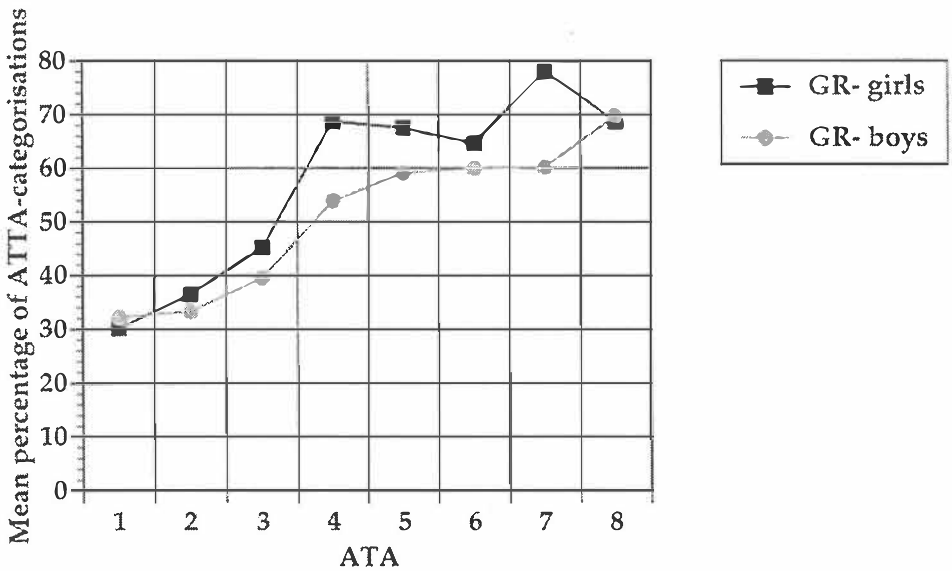

FIGURE 34 The categorisation function for the girl and boy infants in the GR- group. These functions are similar but there is a statistically significant difference in responding to *ata7* (Pearson x^2 = 6,28308, P = .01219) with the boys making less *atta*-categorisations.

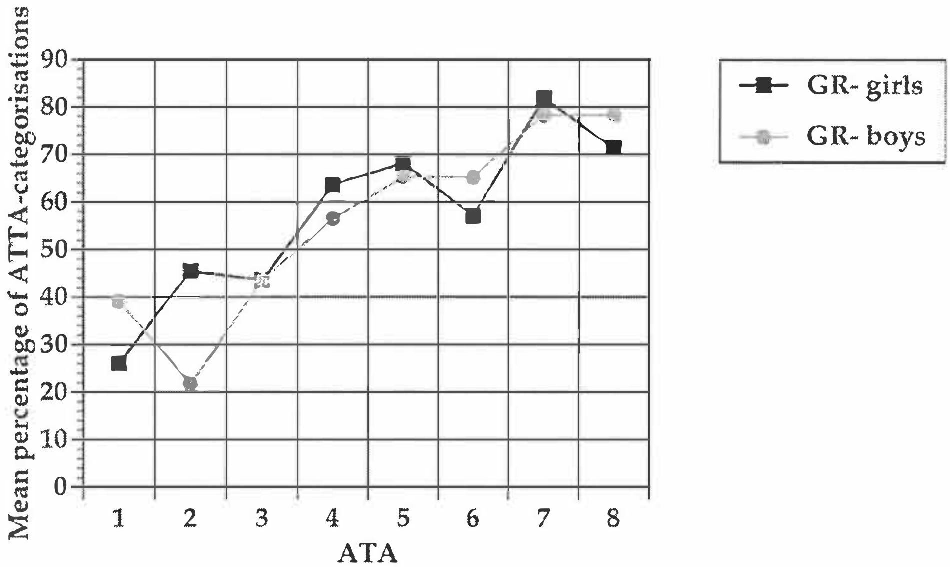

FIGURE 35 The first-time trial data for the girl and boy infants in the GR- group. There are no statistically significant difference between these subject groups.

The last detail of the results which will be examined is the data in terms of the wake-up trials. As in the earlier practice phase, wake-up trials were employed in the cases in which the infants failed to turn their heads in three consecutive change trials. In the categorisation phase there were 39 infants who did not need to have any wake-up trials. Thirty-three of the infants needed to have one wake-up trial, 10 needed two, 5 needed three, one needed 4, and one 5 wake-up trials. The ANOVA showed that there was no group difference between the GR+ and GR- or the girl and boys infant groups in this respect.

3.5 Conclusion

Six month old infants are able to categorise speech sounds according to durational variations. The categorical functions show similar tendencies to those of the adults. However, clear indications of developmental differences surfaced: the categorical boundaries were located further along the continuum in the infant data in comparison to the adult data. This was expected on the basis of previous research. The categories were not as distinct in the infant data in comparison to the adult data. The fact that the infants were very young is believed to explain this tendency at least partly: the task was relatively long for such young infants to stay motivated and attentive.

In terms of dyslexia, the results of this experiment were significant. The results demonstrated that infants with a high genetic risk for dyslexia need remarkably longer sound duration in comparison to infants with no such risk in order to change the quantity category from short to long. The adult data showed similar tendencies but to a lesser extent. The adult results showed that although in general the dyslexics had more variability in their responses in comparison to the control adults the main contribution to the group differences was made by certain individuals who clearly demonstrated an auditory temporal processing deficiency in perceiving speech sounds with varying durations. Thus, the results confirm the hypothesis of this study. This finding was interpreted as showing that infants who may be dyslexics and adults dyslexics to a different extents have a temporal processing deficiency specifically with perceiving speech sounds of short durations. Reasons like lack of motivation, attentiveness, or developmental aspects may be behind the GR+ and GR- infant group results as well. Since the first-time data showed similar trends to the total-time trial data, it is not very plausible that attentional and other features like that could explain the differences. Moreover, the fact that Experiment 3 with adult subjects showed similar tendencies between dyslexics and nondyslexics to Experiment 4 together with similar evidence from several previous dyslexia studies supports the claim that temporal ability may differentiate at least some dyslexics from nondyslexics. However, aspects of auditory memory for temporal information and abstract representations of perceived linguistic stimuli could have caused the present results. These factors need to be studied in the future. Although the infant results strongly suggest that temporal processing ability is an early precursor for dyslexia, the results need to replicated. In addition, since the group results were very prominent more research is warranted in order to gain information also on individuals by collecting considerably more data from each individual.

4 CATEGORISATION ACCORDING TO SOUND DURATION IN DYSLEXIA: PRODUCTION

4.1 Purpose

The objectives of the present chapter are manifold. First, the abilities of 18-month-old infants from the Finnish-speaking environment to use duration in elicited imitations of minimal pairs with the two quantity degrees are investigated. Secondly, the dyslexia aspect is investigated in comparing the productions of the infants with high genetic risk for dyslexia (GR+) to those of the infants with no such risk (GR-). Thirdly, the durational aspects of adult productions of a minimal word pair containing the two quantity degrees are elucidated especially focusing on the productions of the dyslexic adults. Finally, the productions of the adults are used as points of reference in examining those of infants, and here, too, comparisons between dyslexia groups and control groups are made.

The durational aspects of quantity production in Finnish have been investigated in the past (Lehtonen 1970). Whereas Lehtonen's study gave strong indications of how the durational features of speech are used in standard Finnish in adult speakers, we have little information on the durational aspects of quantity production in infants. Furthermore, information on the temporal dimensions of speech production in dyslexics is clearly behind that gained by the many studies that have focused on their perceptual abilities. It is considered important here to study also speech productions since there was evidence of deviations in the dyslexia groups in the perception experiments. For some time now, speech perception and production have been viewed with an underlying assumption that the two sides of communication are interrelated. Therefore, this study attempts to elucidate both of these sides by means of experimental data. The previous chapter dealt with the perception of the dyslexic adults and their children. The production of quantity degrees is studied here in two experiments: Experiment 5 focuses on the production of quantity degrees in the adults, at the same time providing the bases for the comparison between the production data of adults and that of the infants, and in Experiment 6 the productions of the infant subjects are studied. Before the description of the two experiments, information available on the durational aspects of production of the two quantity degrees in Finnish as well as evidence on the temporal dimensions of the speech production of dyslexics are reviewed briefly.

4.2 Duration in production of quantity by adults and children

The most extensive study on durational aspects of the quantity distinction in adult speakers of Finnish is the dissertation of Lehtonen (1970). He found that the distinction was made primarily in the duration of word medial consonants in CVCV/CVCCV structures, but also that the duration of word final vowels and to a the lesser extent that of the first vowel play a role in this distinction. The Table 3 in which the approximate durations of Lehtonen's study are presented, shows that the distinction was also made in the proportional durations. The data of Lehtonen is used as a point of reference here since the speakers in his investigation originated from the same area as the speakers of the present study. However, since the task employed in his study involved relatively highly educated speakers reading sentences aloud the data could be seen as representative of standard Finnish. On the other hand, other less comprehensive studies on the Finnish quantity distinction revealed that regardless of the background of the speakers the quantity distinction seem to be made principally in a similar manner in spontaneous speech as compared to speech elicited by reading tasks (Engstrand & Krull 1994b). In spontaneous speech the most noticeable durational variation occurred in word final vowels in CVCV structures in comparison to utterances which were read (for more information see Wiik's study on Finnish dialects in Chapter 2, page 27). Another point of divergence is formed by the results of Hurme and Sonninen (1982) which contradicted Lehtonen's results in as much as they did not find statistical differences between CVCV/CVCCV structures in V1 durations. It should be noted, however, that the data of Hurme and Sonninen was limited (10 speakers producing 13 words). In sum, it seems that the difference between CVCV and CVCCV structures is indisputably made by adult speakers of Finnish in the duration of the word medial consonant and in the word final vowel, and less consistently in that of the first vowel.

The durational aspects of production of the quantity distinction have been studied to a lesser degree in children. Iivonen (1990, 1993, 1994) who studied his own two Finnish speaking sons reported that one of the boys seemed to master consonantal quantity aspects by the age of 1;7 years and the other son at the age of 2;5 years. Similarly, Oksaar (1983) reported piecemeal evidence on the acquisition of the quantity distinction in Estonian by observing that it is mastered by the age of 2;1-2;3 years. Since neither of the above mentioned studies actually measured durations, the information provided is necessarily restricted as to the extent to which it is comparable to the information provided by the present study and some other pervious studies.

TABLE 3 Average duration in milliseconds of V1 and V2 and word medial consonants in Finnish CVCV and CVCCV words. The same information is also shown in proportional distributions (Adapted from Lehtonen 1970. The statistical difference was calculated by the present writer.)

	C1		V1		C2		V2	
	msec	%	msec	%	msec	%	msec	%
CVCV	73	23	64	20	81	25	105	32
CVCCV	69	20	77	22	152	44	48	14

Hurme and Sonninen measured durations in the production of children. They administered two experiments (Hurme & Sonninen, 1982 & 1985) in which two to six year old children from Central Finland with no known language or speech defects served as subjects[1]. In the earlier study of theirs (1982) the data were elucidated by means of a picture-naming task. The results revealed that approximately 30% of the ten 2 to 4 year old children made a statistically significant difference in the word medial consonant in CVCV/CVCCV structures, whereas the corresponding percentage was 80 in 5 to 6 year old children. Only 20 to 30 percent of the children in both age groups made a systematic distinction in the durations of word final vowels. In the case of V1, less than 10 percent of the older children made a difference between the two structures whereas none of the younger subjects produced this difference. In the study using an utterance repetition task, Hurme and Sonninen (1985) studied the same aspects in ten three year old and ten six year old children with no known speech or language disorders. They found that C/CC distinction in the CVCV/ CVCCV structures was made by 70 to 90 percent[2] of the 3 year old children. The same distinction was made by 90 to 100 percent of the older children. The duration of the word final vowel was systematically used in differentiating the two structures by 40 to 50 per cent of the younger children and by 50 to 70 per cent by the older children. Hurme and Sonninen noted that in general there was greater variance in the productions of the younger children. They concluded that there was a developmental trend in their data showing that the primary distinction between C/CC was mastered earlier than the secondary V2 durational cue (see the details in Table 4). Although the data is relatively limited in the two studies of Hurme and

1 In the 1982 study, Hurme and Sonninen also investigated the performance of hearing-impaired children, but these results are not considered relevant to the presenst study and are not reported here.

2 The data were collected from the productions of two minimal word pairs (*kati/katti* and *mato/matto*) and thus the results reflect these two data.

Sonninen, this data serves here as a point of reference to the productions of infants. Furthermore, the children in their study originated from the same area as the children in the present study and thus their data is comparable to the data collected here.

TABLE 4 Mean durations of sounds in the words *mato* and *matto* in 3 and 6 year old children in Hurme and Sonninen's data. (Adapted from Hurme & Sonninen 1985). The percentages could not be measured since the whole word durations were not provided (the duration of the word initial nasal was not measured in their data).

	mato		matto	
	3 year olds	6 year olds	3 year olds	6 year olds
/a/:msec	102	95	99	103
/t/ :msec	127	111	207	194
/o/:msec	104	115	76	71

4.3 Aspects of speech production in dyslexics

The durational aspects of quantity production has not yet been studied in dyslexics. In general, the temporal aspects of the production side of communication has been studied to a much lesser extent than that of the perception side. Accordingly, the information gained in a number of perceptual studies indicating differences between dyslexics and controls is clearly out of balance with the scant information provided by a handful of studies on temporal aspects of dyslexics' speech production skills. This is clearly a defect in light of one of the prevalent views among linguists that the two sides of communication may reflect each other (e.g., Ingram 1989), and, thus, deviations in the perceptual side of communication may have consequences in production or vice versa. In order to gain a perspective on the speech production side of dyslexics a brief review of the studies on production that are connected with temporality is provided here.

The only study up to present day which deals purely with the durational aspects of speech production in dyslexics is the master's thesis of Scanlon (1994). As well as studying the accuracy, she also studied the articulation rate of syllables and the overall duration of utterances in the speech of an 8 year old girl in comparison to that of a 8 year old boy. The children were studied in pseudoword repetition task, in a disyllabic tongue twister[1] repetition task, and in a sentence[2] repetitions task. Scanlon (1994) found that the speech of the

1 In the tongue twister task the subjects were required to repeat 11 times four disyllabic words.

2 In the sentence repetition task proper English words were used in four short sentences.

dyslexic subject was significantly faster than that of the control subject. As to the accuracy measure, Scanlon found that the dyslexic subject made significantly more errors than the control subject in the pseudoword repetition task. Furthermore, the performance of the dyslexic subject was significantly more variable between the two testing sessions in comparison to that of the control subject. Scanlon concluded that the dyslexic subject had considerable more difficulties with accuracy in comparisons to the control subject, especially with the pseudoword repetition task. Also the dyslexics' performance was more variable between the two testing sessions than was that of the control subject. She suggested that the dyslexic subject's tendency to produce the stimuli at a faster rate may have had a compromising effect on her phonological accuracy performance, and that consequently, or in addition, she was unable to sufficiently monitor her performance. When examining the evidence provided by Scanlon's study several aspects need to be emphasised. First, because it is restricted to the relatively small data of one dyslexic subject the results of this study are not easily generalisable. Secondly, some methodological aspects, for instance the fact that the material to be repeated was produced by the experimenter live in the testing situations, should have been more controlled in order to facilitate the interpretation of the results. Further evidence is needed in order to draw reliable conclusions on the temporal aspects of dyslexics speech. Furthermore, simply by the virtue of the fact that Scanlon's study focused on the rate of articulation her results are not directly relevant to the present study.

Brady, Shankweiler and Mann (1983) also studied dyslexic children's production of speech in a word repetition task. They employed among other things tasks in which 8 to 9 year-old children were required to repeat monosyllabic words either with or without masking noise. Whereas they found no difference in the performance of the subject groups in the condition without masking noise, in the masking noise condition the dyslexic children missed the stop consonants significantly more often than did the control children (Brady et al. 1983, 360). Brady et al. (1983, 360) suggested that this finding could be an indicator of the particular difficulties of dyslexics in processing stops but they considered more likely the possibility that the employed masking noise[1] was of the type that particularly affected the perception of stops. Clearly the former speculation cannot be valid on the grounds of the evidence of their study, since the two subject groups performed equally well in the condition with no masking noise with exactly the same stimuli. An important aspect of the results to be taken in consideration is the fact that the performance levels were at ceiling levels with both of the subject groups, and thus the test may not have been successful in assessing group difference in ideal listening conditions. However, the fact that the temporal features of the signal were retained in the masking noise whereas the spectrum was not, may have had an effect on the perception of the target stimuli. Since stop sounds include rapid transitions the conflicting information of the noise signal and the target signal may have had a

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1 The words were masked by a noise signal which was formed by computing it directly from each digitized speech signal to be masked. The masked noise had the same time-varying characteristics as the speech signal but the spectrum was flattened by a long-term frequency spectrum. (Brady et al. 1983, 356-357).

complicating effect in the perception of the temporal features of the target signal. If dyslexics have problems with the temporal dimensions of speech this factor could partly explain the poorer performance of the dyslexics in this task. In fact, this speculation is further warranted by their other experiment (Brady et al. 1983), in which they found that there was no difference between the subject groups in identifying environmental sounds with masking noise. The idea that the dyslexics may have had problems with temporal cues in the perception of inherently rapid stop sounds which were reflected in the production of the sounds makes the study of Brady and her colleagues relevant to the present study which has similar hypothesis.

Snowling, Goulandris, Bowlby and Howell (1986) experiments were similar to that of Brady et al. The children, which were divided into groups of 9 to 12 year old dyslexic children and their age matched and reading age matched controls, were required to repeat monosyllabic stimuli in both noise masking condition[1] and without masking signal condition. The stimuli consisted of both words (divided into high and low frequency classes) and pseudowords (which were constructed from real words by changing an initial feature of the real word used in the study). Their data showed that dyslexics did not differ from the controls in repeating high frequency words with or without noise but that their performance differed significantly from the controls when repeating low frequency words and pseudowords in both of the listening conditions[2]. The performance in the lexical decision tasks was also poorer in the dyslexia group than in the control groups. Snowling and her colleagues (1986) concluded that their results suggest that dyslexics seemed to have difficulties with segmentation.

Before drawing conclusions regarding the evidence provided by Snowling et al., however, one should consider the fact that the pseudowords employed in their study included words like "gake" (derived from "cake") and, thus, the lexically conflicting information in the stimuli may have lead the performance of the dyslexics astray. It is conceivable that the dyslexics relied more heavily on contextual information than did the control subjects and thus they were not able to analyze the stimuli to the extent the control group subjects did. Another aspect of the choice of stimuli in the experiments of Snowling et al. is that by changing the initial sounds of the real words when making the pseudowords, in half of the words this meant a change in the voicing of stop sounds. In English (the language used in their study) this entails that the temporal characteristics were changed by means of VOT values between the real words and pseudowords. Thus, the dyslexics' difficulties with the temporal dimension may have had an effect at least partly on Snowling et al.'s results. An unfortunate detail about their study is that, while claiming to be an extension of Brady et al.'s study, Snowling et al. failed to do the same error analysis as Brady et al. did and thus were not able to provide further

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1 The noise masking condition used in the study of Snowling et al. (1986) was constructed using exactly the same method as Brady et al. (1983) had employed.

2 Interestingly, Snowling et al's results did not agree with the results of Brady' et al which indicated that dyslexics were more affected by the masking noise than the control children. Snowling et al. speculate that the fixed order of presntation (noise condition always first) in the Brady et al.' study may have affected their results.

evidence on the possible problems of dyslexics in the processing of stop consonants. In conclusion, it seems that there was a difference in the dyslexics and the controls in the study of Snowling et al. in processing phonological information, with the dyslexics either failing to perceive the crucial characteristics of sounds or relying more heavily on the previously acquired lexicon or both. Furthermore, since Snowling et al., also found differences between the subject groups in the lexical decision tasks, it may be tempting to consider the possibility that the results reflected the dyslexics possible difficulties with producing the required sounds (e.g. gake) with significant temporal cues. This explanation is not plausible here, however, since the subjects did not need to repeat the words but rather indicated their responses by yes or no answers.

In addition to studying accuracy, Brady, Poggie and Rapala (1989) studied children's reaction times in repetition tasks with monosyllabic, multisyllabic and pseudoword stimuli. They found no group differences in the reaction times between the subjects with different reading abilities. In the accuracy measure, the poor readers, who were tested to be at least 9 months behind the average reading level of their age children (8-9 year olds), were significantly less accurate at repeating the multisyllabic and pseudoword stimuli than the above average readers. Brady et al. (1989, 120) speculated that the reason why there were no reaction time differences could have been that the subjects did not have severe problems with reading ability and that the children were too old to demonstrate any basic differences in the speed of processing. They (1989) concluded that their evidence suggests that poor readers have encoding problems but that they are not slower than average readers. The fact that the dyslexics in their study were not slower than the controls is interesting in light of the findings of Experiment 3. Here the dyslexic adults were significantly slower than the controls in their *atta*-responses. But since the two studies dealt with the two different sides of the communication, i.e., perception and production, these findings are not directly comparable.

In a more recent study, Stone and Brady (1995) extended the findings of Brady et al.'s study (1989) by studying the same age children with the similar subject sampling screening criteria. Their evidence gave further affirmative evidence on poor readers difficulties with accuracy in the pseudoword repetitions tasks among other tasks, but also that their performance was not significantly slower than that of their agemates and younger reading level matched children. As the researchers themselves noted (1989, 120; 1995, 112) their evidence may be limited since the subjects were not necessarily severely dyslexics, and, therefore, their evidence is not directly applicable to severely dyslexic populations. However, there exists ample evidence, some of it not reviewed here (Brady et al. 1989, Stone & Brady 1995, Catts 1986, Kamhi and Catts 1986, Kamhi, Catts, Mauer, Apel and Gentry 1988, Catts 1989, 1993, Hansen & Bowey 1994, Apthorp 1995), that dyslexics have difficulties with accuracy scores in speech repetition tasks especially with pseudowords. Thus, it seems that performance in the pseudoword repetition tasks reflects onto the output phonological level the possible difficulties dyslexics have with phonological processing. If it is assumed that perception abilities are reflected in production abilities then the difficulties observed in perception of duration in quantity categorisation in Finnish may also be reflected in production. On the basis of this idea, the durational dimensions of speech production in connection with dyslexia is studied in the following two experiments.

4.4 Experiment 5

4.4.1 Research questions

Previous research on quantity distinctions in the speech of Finnish speakers has shown that the two degrees are kept apart in a distinct way between CVCV and CVCCV structures, and this distinction is apparent in the durations of the speech segments (e.g., Lehtonen 1970, Iivonen 1974a & b, Hurme & Sonninen 1982 & 1985, Engstrand and Krull 1994a & b, Hirvonen 1992). No equivalent information exists on the speech of Finnish speaking dyslexics. Here the durational dimensions of the quantity categories are investigated in an experiment with the same adult dyslexics who participated in the adult perception experiment in this study. The material was collected from the situation in which the adults were trying to make their 18 month old infants imitate words that they used when naming pictures from the picture cards. The following research questions are asked:

1. How are the two quantity categories manifested durationally (physical duration and proportional duration) in the control adults from the Finnish-speaking environment in producing the minimal word pair *mato* and *matto*? More specifically, how is the distinction between CVCV and CVCCV structures made durationally?

2. How are the same aspects manifested in the dyslexic adults producing the same words?

3. Do the productions of the dyslexic adults differ from those of the control adults in the durational dimensions?

4.4.2 Method

4.4.2.1 Subjects

The speech production data were collected from twenty-two dyslexic adults and thirty-one control adults[1]; the same subjects participated also in Experiment 3. Of the dyslexic adults 17 were female and 5 male, and the corresponding figures were 25 and 5 respectively in the adult control group. The mean age of the adults was 33 for the dyslexics and 35 for the controls. All the adults had normal hearing and none of them had articulation defects according to their own report.

4.4.2.2 Linguistic material and procedure

The linguistic material of this experiment consisted of the minimal pair *mato* and *matto*. The words were written on two picture cards underneath a drawing of each object. In the oral instructions each drawing was named by the experimenter and it was pointed out that the words were also written underneath the drawing as a reminder of the words the adults were required to produce. The adults were instructed to say each word in a manner they thought would best get their child to respond by imitating the word. There were no limitations as to how many times to say each word. Only one production of each word from each of the subjects was included in the analysis of the data. The aim was that the child would repeat each word once. If it appeared that the child was not going to repeat the words then the test was discontinued. Usually the parents and infants were looking at the picture cards for approximately 10 minutes.

4.4.2.3 Apparatus and segmentation conventions

All the words produced by the adults were recorded on a DAT tape using an AKG microphone. All the words were digitised using a sampling rate of 22 kHz with a 5 kHz low pass filtering and with the GW Instruments SoundScope software together with a Power Macintosh (7600). The durations were

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1 These data were not collected from all the parents participating in the two dyslexia projects for several reasons. First, in the cases in which an infant imitated adequately in a video elicited imitation task, which was conducted before the picture naming repetition task in half of the cases the picture naming repetition task from which the adults productions were analysed was not conducted. Secondly, in some of the cases the children were not co-opertative and did not do the task (started crying, did not stay in the testing room, were sleepy etc.) and therefore the adults did not have an opportunity to produce the words. Thirdly, some dyslexic adults were unable to come to the laboratory with the infants because of their work or because their had fallen ill.

measured and the phonetic quality was examined using wide-band spectrograms together with waveforms and intensity curve. Both visual and auditory cues were utilised in the analysis. Illustrations of the segmentation conventions are given in Fig. 36, in which an example of the spectrogram representation of the word *mato* is shown displaying the locations of the segment boundaries. The segmentation conventions employed here are the following:

CONSONANT 1 /m/ = The duration of the word initial nasal was measured from the point at which the voicing began, while the intensity curve was measured from down or almost down to the point at which the wave-form changes and the intensity curve rises steeply (thus including the murmur state and the transition).

VOWEL 1 /a/ = The duration of the first vowel preceding the word medial stop, was measured from the point at which the preceding nasal finished to the beginning of the formant transition of the following consonant.

CONSONANT 2 /t/ = The duration of the word medial stop was measured from the point at which the occlusion of the stop begins (voice offset time, i.e., the time interval measured from the beginning of the occlusion to the point at which voicing of the preceding sound ceases, was included) to the beginning of the voicing of the following vowel (vocalic formant structure), thus including the burst and the short voiceless period[1] between the burst and the beginning of the voicing.

VOWEL 2 /o/ = The duration of the vowel following the word medial stop, was measured from the point at which the voicing commences after the release of the stop to the point in the waveform at which the voicing ends.

TOTAL /mato/ = The duration of the whole word was measured from the beginning of the voicing of the word, the location from which the word initial nasal started, to the end of the voicing of the word final vowel.

1 In Finnish the plosives are not usually aspirated (e.g., Lehtonen 1970, Suomi 1980).

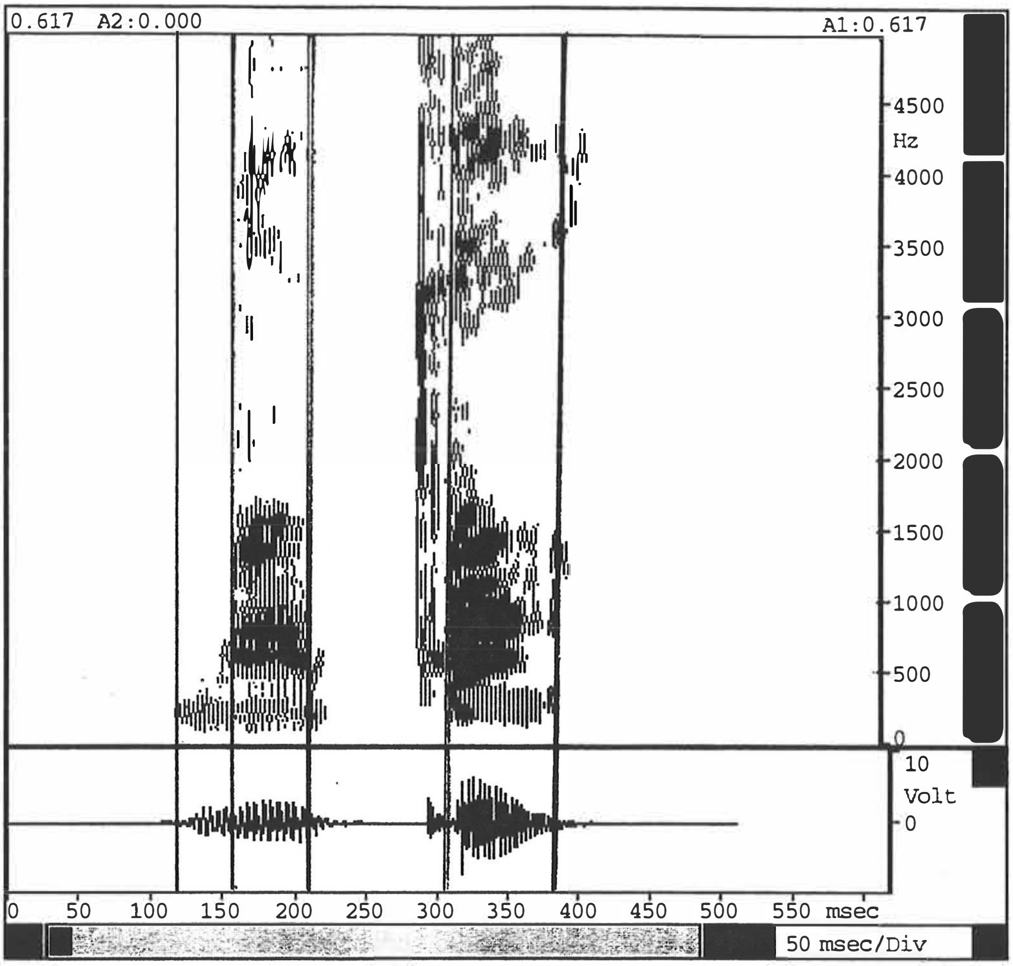

FIGURE 36 Speech wave and spectrogram representations of the word *mato* illustrating the segmentation conventions employed in the present study.

Similar segmentation conventions were also employed in Lehtonen' s (1970) study, which forms a point of reference for the present study. Proportional measures were counted on the bases of the segmental measurements. By doing this, an attempt was made to avoid the effects of speech rate on the results. Previous research has indicated that durational relations in utterances are more consistent than absolute measurements between different speech tempos (Port 1977, 1982).

The segmentation of the acoustic signal proved to be straightforward. Obviously it is well known to phoneticians that there is always a certain amount of subjective evaluation in the process of locating the points of division between speech segments. In addition to coarticulation, there are many reasons for this, which have been discussed in the ongoing debate on speech segments, concerning their existence and size (a single sound? a syllable? a word? etc.

(e.g., Dufva 1991, 153). Only those words which were surrounded by silence were included in the measurements. This was done in order to avoid segmentation problems, and because the majority of the words were produced in that way.

Since the main purpose of this experiment was to investigate the contribution of durational cues, all the segments of the stimuli were systematically measured as well as the whole duration of the word. Measurements were rounded to the nearest millisecond. The durations of the word initial nasal, the first vowel, the stop and the word final vowel were measured as well as the durations of the whole words and all the durations measurements are given in Table 5. Also the proportional measurements are given in the table.

The measurements were tested for consistency by remeasuring 50% of the words half a year after the first measurements. The measurements were compared and their difference yielded a Pearson correlation coefficient of .991 on segment durations. Thus, the measurements can be considered to be consistent. In addition, another phonetician measured segmental durations of 25% of the data. These measurements in comparison to the original measurements yielded a Pearson correlation coefficient of .990. Thus, the measurements have been done systematically, and in this way they do not affect the results of this data.

4.4.3 Results and discussion

One production of each of the words was included in the analysis from all the adults, making a total of 104 words. The quality of the sound segments in the subjects' speech was unambiguous in all the cases. Paradigmatic analyses are examined firsts.

The data were first analysed to discover how the word structures CVCV and CVCCV were kept apart durationally by the control adults. The means and standard deviations for each of the measures as well as the proportional durations are presented in Table 5. These values (both in milliseconds and in percentages) were compared between the two word structures and the statistically significant differences were established by means of the t-tests for paired samples. The results reveal that the absolute measures (i.e., the ones measured in milliseconds) differed in the productions of the control adults only in the durations of the word medial consonant and the word final vowel. There was a highly significant difference between the word medial consonants with that of the CVCCV structure being almost three times as long as that of the CVCV structure. Also there was a highly significant difference in the word final vowels with that of the CVCV structure being almost twice as long in duration in comparison to that of the CVCCV structure. Naturally, the difference in the total duration between the two word structures was also highly significant. Proportionally, all the differences in the measures were statistically highly significant, except the difference between the word initial consonant which reached almost a significant difference level. These results are in accordance with those of Lehtonen. It should be pointed out that in terms of the durational distinction between V1 in CVCV and CVCCV words these results disagree with the results of Hurme and Sonninen (1982) since their results did not indicate a difference in the first vowel of the word. As was pointed out earlier their data were limited in size and this may explain the fact that the difference did not occur in their data.

In conclusion, the structures CVCV and CVCCV with different word medial quantity degrees are distinctly kept apart in the durations of segments in the speech of the Finnish speaking adults. Although proportionally it appeared that all the segments were durationally distinct, the distinction can be attributed particularly to the word medial consonant and the word final vowel. Both seem to be important cues for the quantity distinctions of the two word structures in question.

TABLE 5 Means and standard deviations (SD) in milliseconds and in percentages of the different sound segments in the word *mato* and *matto* produced by the control adults. The statistical significance of the differences between the CVCV and CVCCV structures is marked in the right hand column (*p < .05, **p< .01, ***p<.001).

		Mato		vs		*Matto*		
Parameters	*n*	*Mean*	*SD*		*n*	*Mean*	*SD*	*Sig.*
/m/: ms	30	64	28		30	67	26	NS
/a/: ms		84	42			87	20	NS
/t/: ms		118	28			319	95	***
/o/: ms		163	71			88	24	***
/m/: %		15	5			12	4	*
/a/: %		19	5			16	3	***
/t/: %		29	7			56	8	***
/o/: %		37	9			16	4	***
/o/:/a/		2.2	1.2			1.0	.2	***
/o/:/t/		1.4	.7			3.9	1.7	***
total		429	126			560	125	***

In order to investigate the dyslexic adults' durational distinctions between the two word structures, the data of the dyslexic adults were analysed next. The data and the descriptive statistics of the productions are presented in Table 6. The results of the dyslexic adults show that they also distinctly separated the word medial consonants in absolute durations in the two word structures in a similar manner to the control adults. However, the results of the two subject groups differ with respect to the absolute durations of the word final vowels: the dyslexic adults did not make a statistically significant difference in the absolute durations whereas the controls did. Proportionally, however, the differences in the two word structures reached a statistically significant level in all of the segments except in the word initial segment. These results are comparable to those of the control adults. The results of the both subjects groups were also similar to the extent that there was a relatively great variation in the durations of C2 and V2 between the subjects of the both groups. The variability element of durational measures was expected since previous research has shown that in durational studies there can be a considerable amount of variability in speech sound durations within productions of one speaker as well as between different speakers (e.g., Klatt 1976, 1208; Pickett, Bunnell & Revoile 1995, 4).

Syntagmatically the durations of the first vowel and the word final vowel in the two word structures were not produced differently by the dyslexic adults. These relations between the two word structures were statistically highly significant in the control adults' data. This difference between the two subject groups demonstrates the fact that the dyslexics did not produce the word final vowel of the *mato* word with as long a word final vowel as the controls. Also since there is a tendency to make the total durations of words similar regardless of the structure this relatively short duration of V2 affected the duration of V1 to be relatively long. The other syntagmatic relation under study, i.e., the relation between the duration of the intervocal consonant and the word final vowel in the two word structures, were produced similarly between the two subject groups with a highly significant difference between the two words. Thus, it appears that the syntagmatic relations showed similar tendencies of the data as did the paradigmatic features.

TABLE 6 Means and standard deviations (SD) in milliseconds and in percentages of the different sound segments in the word *mato* and *matto* produced by the dyslexic adults. The statistical significance of the differences between the CVCV and CVCCV structures is marked in the last column on the right (*p < .05, **p< .01, ***p<.001).

	Mato			vs	*Matto*			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*		*Sig.*
/m/: ms	22	74	31	22	85	36		NS
/a/: ms		103	34		96	28		NS
/t/: ms		127	32		359	82		***
/o/: ms		134	67		97	29		NS
/m/: %		17	6		13	5		NS
/a/: %		23	7		15	3		***
/t/: %		30	9		56	7		***
/o/: %		29	11		15	4		***
/o/:/a/		1.4	.7		1.1	.4		NS
/o/:/t/		1.1	.5		3.9	1.2		***
total		439	98		637	133		***

It seems that dyslexic adults were capable of producing the durational differences of the two words with a different quantity structure in a similar manner to the control adults. The only deviation in the results was the difference in the way the word final vowel was used durationally in the two word structures between the dyslexics and the controls. The controls made clearer differences in comparison to the dyslexics in this respect. This could be a dialectical difference between the two subject groups, since there is evidence that this is the feature in which durational difference are apparent (Wiik 1985). This could also be an indication of a temporal deficiency in the speech production of the dyslexic adults. It could be speculated that if dyslexics have temporal deficiency in the perception of speech sounds they may also have problems with attending to many different durational features of the speech signal or organising these durational differences or relationships while speaking. Thus, they may be able to produce an adequate difference in the place of the major cue for the quantity distinction between the CVCV and CVCCV structures but do not notice or cannot make the durational relationship adequately of the slightly subtler durational cue in the word structures in question. However, it should be remembered that the relative shortness of the word final vowel does not affect the meaning of the word, so the linguistic significance of the statistical difference found in the word final vowel durations between the subject groups is questionable. Neither is this kind of shortness easily discernible since speech sounds are usually perceived as short or long and as listeners we do not listen to the absolute durations but the function of the words.

In order to further compare the productions of the two subject groups, the data were statistically analysed using an analysis of variance test (ANOVA). First the data of production of the word *mato* is investigated. The measurements of the absolute durations were similar in the two subject groups (see Table 7 for the details). The perceptual measurements yielded some significant differences between the subject groups. There was a significant difference in the proportional measurements of the first vowel as well as in those of the word final vowel (ANOVA F 6.4567, P .014, and ANOVA F 7.5303, P .008, respectively). These results demonstrate that proportionally the dyslexics made a lesser distinction in comparison to the control adults in the two vowels of the CVCV structure. The difference in the word final vowel between the two subject groups was virtually highly significant with the control adults having remarkably longer duration in the word final vowel. However, as was mentioned earlier, this difference may be an indication of a dialectical feature. The word final vowel in structures like CVCV plays an important part but can still be considered to have a somewhat secondary role in the quantity distinction in CVCV structure words.

Syntagmatical analyses of the data revealed that the dyslexic adults and the control adults made had a different kind of durational relationship between the segments in the *mato* word. It appears that the difference between the two subject groups emerged in both of the syntagmatic relations in question. These results are explained by the fact that the control adults differentiated durationally /V1/, /C/ and /V2/ from each other whereas the dyslexic adults had relatively similar durations in all of these segments.

TABLE 7 The mean durations and standard deviations in the *mato* word produced by the control adults and the dyslexic adults.

	Control Adults			Dyslexic Adults			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
mato:/m/:ms	30	66	30	22	75	32	NS
mato: /a/:ms		84	41		101	33	NS
mato: /t:/ms		118	28		132	37	NS
mato: /o/: ms		168	74		140	70	NS
mato: /m/:%		15	5		17	6	NS
mato: /a/:%		19	5		23	6	**
mato: /t/:%		28	7		30	8	NS
mato: /o/:%		38	9		30	11	**
mato: /o/:/a/		2.2	1.2		1.5	.7	**
mato: /o/:/t/		1.5	.7		1.1	.5	*
total: ms		436	130		448	109	NS

The descriptive data of the *matto* word productions in the two subject groups is presented in Table 8. As the table shows, durationally (both in absolute measurements and in proportional measurements) the dyslexic adults made the differences between the segments in a similar manner to those of the control adults in this word structure. Since previous research has indicated that there are no remarkable dialectical differences in this structure, the possible dialectical differences between the subject groups did not affect these results.

In conclusion, it appears that there are some differences in the CVCV word production between the dyslexics and the controls in the present study. However, these differences may be attributable to the dialectical variations of the speakers in the two groups, since otherwise the durational aspects of productions between the two subject groups do not differ. There is a possibility that these dyslexics do not use the secondary cue for quantity in the CVCV structure as effectively as the control adults. However, they produced the primary cue distinction in consonant duration in virtually the same way as the control adults. The durational relationships may be more difficult for them to execute in their speech production. This relational factor may also be reflected in their speech perception. In the perception experiment only the duration of the primary cue was varied leaving the duration of the word final vowel untouched. As was noted in Chapter 3 a large number of the dyslexic adults categorised the primary cue similarly to the control adults. Perhaps the nature of the perception stimuli and the task made the adults focus only on the primary cue and their judgments were based on that. It would be interesting to study the perception of quantity by varying both of the durational cues. In this way the aspect of trading relations of the durational cues in categorisation within the CVCV and CVCCV structures could be elucidated.

TABLE 8 The mean durations and standard deviations in the *matto* word produced by the control adults and the dyslexic adults.

	Control Adults			Dyslexic Adults			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
matto:/m/:ms	30	67	26	22	81	34	NS
matto: /a/:ms		87	20		92	29	NS
matto: /t:/:ms		319	95		357	80	NS
matto: /o/:ms		88	24		93	30	NS
matto: /m/:%		13	5		12	4	NS
matto: /a/:%		15	4		16	3	NS
matto: /t/:%		56	9		56	8	NS
matto:/o/:%		16	4		16	4	NS
matto:/o/:/a/		1	.2		1.1	.4	NS
matto: /t/:/o/		3.9	1.7		4.1	1.6	NS
total: ms		617	121		560	125	NS

The fact that the gender distribution in this experiment was uneven, could be reflected in the results. However, the results of the males, who were a minority here, did not differ significantly in any of the measurements from those of the females. In the future, the gender aspect should be studied further since there were indications in the perception experiment that there was a difference between the two genders in categorising the stimuli. Here the gender distribution was affected by the fact that more of the male dyslexics in comparison to females could not come to be tested because of their work or similar reasons to that. The same applies to the control group.

Another unfortunate factor concerning the data is that only two of those dyslexic adults (both females) whose perception data was deviant participated in this production experiment. The investigation of these individual data revealed that whereas one of the female's productions were durationally similar to the average data of the control adults, the productions of the other female were furthest away in the dyslexia group in the proportional durations from the control adults. This tendency is especially evident in the word *mato* in which the proportional durations of this dyslexic female were the following: m% = 17, a% = 22, t% = 41 and o% = 20 (the respective figures in the average control data were: m% = 15, a% = 19, t% = 28, o% =38). It appears that this adult female dyslexic differed significantly in the temporal aspects of her productions from the control adults. Since her performance also was deviant in the perception experiment with varying durational features of the stimuli, it appears that both her perception and production of speech stimuli are temporally deviant from the average speakers of Finnish. The fact that the other female's production data were similar to the control adults data is important to notice, too. Clearly, only tentative conclusions can be drawn on the basis of these results on the possible relation between the production and perception sides of communication due to the fact that not all the same adults could participate in both of the experiments. However, the variance in the results does suggest that a correlation may exist between perception and production, and future studies may be able to shed more light on this possible correlation.

As a general remark concerning these adult production data, it should be noted that although the experimental situation did not include reading aloud, the situation can be considered to be relatively formal, since the experiments were conducted in the university's laboratory with microphones and video cameras clearly visible to the adults. Thus, it can be presumed that the language of the speakers in this experiment may also have reflected a more formal code. This assumption is, however, contradicted by the fact the data were collected in a situation in which only the adults and their own children were present which presumably entails that the adults speakers were using a more informal speech style to a certain extent. Also the fact that the speech of the adults was directed to their 18 month old infants has an effect on the speech style (cf., to the studies on motherese, e.g., Fernald & Simon 1984, Fernald & Kuhl 1987, Fernald, Taeschner, Dunn, Papousek, Boysson-Bardies & Fukui 1989, Werker & McLeod 1989). Previous research has shown that for example prosodical features[1] of speech are altered in speech directed to infants. Among the altered prosodical features also durational changes in the child directed speech have been noted. For example the study of Malsheen (1980) showed that adults tended to use more delineated VOT values when speaking to children when compared to the overlapping VOT values of voiced and voiceless sounds[2] exhibited in speech between adults. Ratner's data (1986) also showed a tendency for adults' exaggerated durational cues of vowels to indicate clause boundaries when speaking to children. It should be noted though that a somewhat slower rate of speech and increases in the segmental durations of child directed speech do not seem to be used consistently in adults' speech. Typically, durational cues are emphasised in content words which are also often more precisely articulated compared to function words (Ratner 1984 &1986, Morgan 1986, Swanson, Leonard & Gandour 1992). Thus, since the adult speakers in Experiment 5 were directing their speech to their own infants it is likely that this was reflected in the accuracy of their pronunciation and emphasised durational differences of the segments.

As such, information on the parental input in situations like that of the present experiment is valuable since, for instance, it gives an idea how dyslexic parents spoke in comparison to control parents in a standardised communication situation with their young children. In other words, we may be

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1 Previous studies have shown that adults emply empathetic stress, use emphatic stress to highlight a target word, higher overall pitch, employ greater pitch excursions and longer word durations in their speech when speaking to their infants as compared to speech directed to adults (Cooper et al. 1990, Fernald 1984,1985, Fernald et al. 1984, 1987 & 1989, Werker et al. 1989).

2 In Malsheen's (1980) data, the VOT values for intended voiced and voiceless initial stops overlapped up to 60% in speech between adults, but there was only approximately 11% of overlapp in speech directed to children.

able to get an idea whether the parents overemphasise the durational features of their speech by knowing the way in which the distinction should be made. However, the present data cannot answer the question are these parents able to change their speech style and at the same time the durational patterns of speech for formal communication situations like this. For that purpose, the adult productions in the home environment in spontaneous speech should be investigated. Also by studying longer utterances a better picture would be gained of the temporal features of speech productions. It can be speculated that if the speech style was more formal in the experiment, then by knowing the way in which the quantity distinction is made in Finnish they would have emphasised these structures. And if this is the case then the control adults were able to emphasise even the finesses of the differences better than did the dyslexic adults in the same situation. But as was said this is just a speculation and further research is needed to elucidate the aspects mentioned here.

In sum, the results of the adult production experiment showed that Finnish speaking adults make a distinction between *mato* and *matto* words in the durations of the speech sounds. Although Experiment 5 indicates that dyslexic adults are capable of making the durational distinctions between the two word structures in a manner similar to the control adults, the results also indicate that there may be a difference in the way in which the durational cues are utilised in the productions between dyslexic adults and control adults. As a sign of this the dyslexic adults in comparison to the control adults made less of a distinction between the word final vowels between the two word structures. It was speculated that the durational relationship between the major acoustic cues for these word structures may be troublesome for some dyslexics. Alternatively, possible dialectical differences may explain these durational differences.

Experiment 5 provided some evidence also on the temporal aspects of parental input in experimental speech situations with 18 month old infants. The results revealed that as the distinctions between the two word structure with short and long quantity degrees are made clearly in the durations of speech sounds there is a slight difference between dyslexic parents and nondyslexic parents in executing these differences. In general, however, the durational features are produced in a similar manner between dyslexic and nondyslexic parents.

This production experiment can be seen as an initiation of durational research conducted with dyslexic and control adults. Further research is needed specifically on the temporal aspects of spontaneous speech productions with dyslexics in order to elucidate the temporal abilities of dyslexic parents in speech production. In addition, further experimental evidence is needed in order to get affirmative answers whether dyslexic adults have deficiencies in temporal features of speech production.

4.5 Experiment 6

A production experiment was conducted also with 18-month old infants. Here too the durational aspects of quantity production were investigated. The quantity aspect has been studied previously in Finnish children (Hurme & Sonninen 1982, 1985) but the children were considerably older than those who participated here. There are also some observations on the ability of younger children to make the quantity distinction in their speech at around 18-months of age (Iivonen 1994). However, there has been no systematic studies on the quantity production of such young Finnish infants. In addition, in an attempt to discover possible early precursors for dyslexia the productions of two subject groups are studied, one with a high risk for dyslexia and one with no such risk. Needless to say this aspect has not been studied previously. The validity of using temporal parameters in investigating such young children comes from previous research which has demonstrated that temporal coordination in speech production emerges already during the first year of life (e.g., Kent 1976, Koopmans-van Beinum & van der Stelt 1986, Sereno & Liberman 1987). Thus, since Experiment 4 suggested that these same infants had an ability to categorise sounds with varying durations already at the age of six-months, and since there are indications that in spontaneous productions some Finnish children are able to make quantity distinctions at around the age of 18-months, it is hypothesised that the 18-month-old infants studied here would be able to make durational distinctions in producing (C)VCV and (C)VCCV structure words. Furthermore, since there were indications in the perception experiment of a difference in perceiving and categorising according to the durational features of speech between the GR+ infants and the GR- infants, it is hypothesised that the same perceptual differences may be reflected in productions as well. These hypotheses were tested in Experiment 6.

4.5.1 Research questions

In order to find out if the 18-month-old infants are able to use durations in distinguishing the two quantities of the Finnish language in speech productions, an imitation experiment was conducted. To investigate the developmental aspect of the productions, the infant data were compared to those of the adults. Furthermore, the productions of the infants were investigated to discover if there is a difference in the production of the durational dimensions between the GR+ infants and the GR- infants. Also, since the parents of the infants were studied in the previous experiment the data were investigated in light of parental input on the children's speech. Therefore, the GR+ infant data and that of the GR- infants were compared to the data of dyslexic adults and those of the control adults, respectively. In Experiment 6 the following research questions were addressed:

1. Are 18-month-old infants who are learning Finnish able to durationally differentiate words containing long and short quantity degrees in their imitations?

2. Do 18 month-old infants with high genetic risk for dyslexia (GR+) differ in "direct" imitations from infants with no such risk (GR-) in terms of durational aspects (physical duration and proportional duration) of the phonemes in words containing long and short quantities?

3. Is there a difference in durational aspects in the infants' imitations of words compared to pseudowords? Do the two subject groups differ in this respect?

4. Is there a difference in the response times between the two subject groups?

5. Is there a difference between the imitations of the boy infants and those of the girl infants?

6. Do the infants' imitations differ from productions of the same words containing short and long quantity by the adults? Are there group differences in this respect (adults vs infants; dyslexic adults vs GR+ infants; control adults vs GR- infants) ?

4.5.2 Method

4.5.2.1 Subjects

A total of 163 infants participated in Experiment 6; the same subjects who participated in Experiment 4. Seventy-eight of the infants belonged to the genetic risk for dyslexia group (GR+) and 85 infants belonged to the control group (GR-). They ranged in age from 0;17.10 to 0;19.0 (X=0;18.6). Altogether there were 74 females and 89 males: thirty-seven of the females and 41 of the males belonged to the GR+ group and 37 of the females and 48 of the males to the GR- group. Altogether the productions of 64 infants were included in the data, 29 of them belonging to the GR+ group and 35 of them in the GR- group. The gender distribution of the acceptable imitations was the following: 16 girls and 13 boys in the GR+ group and 18 girls and 17 boys in the GR- group. Only the imitations which resembled the adult model productions in the quality of the sounds were analysed here. The attrition rate was 61% in this experiment, which is high, and in the at risk group it was 63 % and 59% in the control group. However, it should be noted that the subject loss in infant experiments like this is usually relatively high. The 99 infants who failed to produce acceptable imitations in the experiment did so for the following reasons: they found the female on the video scary so that the test was discontinued (9), found the female on the video funny and only giggled during the test (5), they failed to stay in the testing room (4), they watched the video attentively but did not imitate (19), their imitations were inaudible (12), their imitations did not resemble the test words (18), they imitated the animal noises but failed to imitate the test words (20), imitations were not analysable because other noises masked them (e.g., speech of the parents, the model productions were presented simultaneously with the imitation, loud noises caused by moving a chair or coughs of the parents, the child had the hiccups) (13). Of the 99 excluded infants (who ranged in age from 17 months, 8 days to 19 months, with a mean age of 18 months 5 days) 49 were assigned to the at risk group and 50 were assigned to the control group. All the infants were learning Finnish in a monolingual Finnish speaking environment. All of the infants were healthy and had no hearing problems.

4.5.2.2 Imitation material

The material which the infants were to imitate included the same pseudowords *ata* and *atta* that were used in the other experiments of the present study. These words were included in order to facilitate the comparison between the perception and production data. In addition, the pseudoword *atta* pronounced with a Swedish gravis accent was included in the test words. This word was included in light of the co-operation with Swedish researchers who use exactly the same imitation experiment with Swedish 18-month-old infants in order to study possible differences between Finnish and Swedish infants concerning the effects of ambient language at this age[1]. The imitations of the "Swedish" *atta* are not included in the presents analysis, however. Instead, a minimal pair of Finnish words, *mato* (a worm) and *matto* (a carpet), differing in the quantity aspect, were included in the experiment. The *mato-matto* stimuli were selected since they are relatively common words even with young infants (in fact approximately 70 %[2] of the parents declared that their 18-month-old infants would have heard one of the words used prior the imitation experiment[3]). In

1 The Swedish replication of the experiment was initiated during 1997 in the phonetics laboratory of the linguistics department at the University of Stockholm by Fancisco Lacerda.

2 The word *matto*was more familiar to the infants than the word *mato*. Ninety-two percent of the infants had heard the word *matto* prior the experiment and only 45 % of the infants had heard the word *mato*.

3 The usefulness and accuracy of parental reports have been previously compared to actual investigations of infants' productions (Fenson 1994, Bates, MacWhinney, Thal, Fenson, Dale, Reznick, Reilly & Hartung 1994, Fenson, Dale, Reznick, Bates, Thal & Pethnick 1994, Lyytinen, Poikkeus & Laakso 1997). Parental reports compare to a large extent very favourably with investigators results of infants vocabulary and therefore parental reports are used increasingly in investigations of language development.

this way we wanted first of all to give infants the option of imitating words with the two quantities in the test situation in case the unfamiliar pseudowords would not be successful in coaxing imitations, and secondly, we wanted to compare the imitations of the presumably familiar words with the unfamiliar pseudowords. The familiarity-unfamiliarity continuum was used in order to study if there was a difference between "direct" imitations (in the case of pseudowords) and possible effect on previously acquired word (in the case of *mato* and *matto* words) of which the infants may have started to have representations in their language. The fact that the parents of these infants had also produced the same minimal pair word facilitated comparison of the infant data to those of the adult data. The imitation material included also two words of animal noises, *miau* (a cat's mew) and *hau hau* (a dog's bark), known to be interesting to infants, in order to coax the infants to imitate in the experimental situation. The imitations of the animal noises were not included in the analyses.

A Finnish speaking female produced all the test words. The female was different to the one who had produced the pseudowords for the other experiments of the present study. Her productions were utilised here since in addition to being a native speaker of Finnish from central Finland she was also fluent in Swedish[1]. This was important in light of the Swedish pronunciation required in the production of the test word *atta*. It should be noted that the recording situation was relatively formal and this may have affected the way in which she was speaking, molding her speech to the way in which educated speakers of Finnish speak in formal situations, i.e., using standard Finnish pronunciation[2].

Each word (seven words altogether) was presented three times on a video tape in random order in blocks of three so that all the words were presented once in each block[3]. If infants imitated a word more than once only the first production was included in the analyses. Only a few of the infants (20 %) produced test words more than once. In the experiment a videotape was played on which the female appeared every 12 seconds to produce one test word twice in a row with a one second interstimulus interval between the words. The tape was prepared so that an exact copy of each word was

1 She has lived in Jyväskylä most of her life since her early childhood. She had spent 4 years in Sweden in her youth and has acted as a lecturer in Swedish in the University. Furthermore, our Swedish collaborators considered her Swedish pronunciation to be compareable to native speakers (native-like).

2 By standard Finnish I mean the form of pronunciation still used largely in the mass media and in educational communication in schools and universities.

3 When the testing started in late autumn 1995 the imitation video tape was made up of four blocks of each word. Also the number of words was larger since some additional animal noises were included in the tape. The silent gaps between the model productions were also longer (approximately 15 seconds long). Since it seemed after the first 20 infants who had been tested with this tape that the attrition rate was high, and since the experimenters and the parents had observed that the infants could not sustain their interest for the time this longer imitation tape lasted (it was virtually 8 minutes long), we shortened the tape by shortening the gaps in between the model words and by extracting some of the test words. After the change the attrition rate dropped to some degree.

produced each time. During the twelve second silent gap the female disappeared and on the monitor a blank yellow picture was shown, and this time served as a response window for the infants. The videotape lasted approximately 5 minutes.

4.5.2.3 Segmentation conventions and apparatus

The segmentation conventions and the apparatus used for the analyses in this infant experiment were identical to those employed in Experiment 5 (see pages 146-149 for details).

Each word imitated by the infants was scored as correct or incorrect. The infants' first imitation performance on each item was coded from the DAT tapes. The response time was defined here as the time that lapsed from the end point of each target word to the onset of the imitations. The response times were measured from the DAT tapes using the SoundScope analysis program.

Exact imitations (the same segments in the same order as in the model) as well as close approximates (*nato* for 'mato') were included in the analyses as correct responses. If the first imitation was not correct then the second imitations of the same words were analysed with the same inclusion criteria for the data. And finally, the third imitations were analysed if the second imitations could not be included in the data. Eighty-eight per cent of the imitations were exact imitations, and nineteen per cent were considered as close approximates. The exact and approximate imitations were combined for the analyses.

The segmentations as well as the quality of the speech sounds were analysed by another phonetician in 25 per cent of the utterances. The agreement between the judgments were of the order of 93%. All disagreements between the two scorerers were resolved through discussions. The segmentation of the spoken utterances did not turn out to be as straightforward as with the adult subjects. This was expected since anyone who has dealt with infant speech productions knows that the same features that are evident in adult productions are not as evident in infant productions. The segmentation was most straightforward in the case of the word medial consonant and the word final vowel. In most of the cases there was an unambiguous point in the spectrogram indicating the beginning of the occlusion in the form of a definite point at which the patterns showed an abrupt change in the overall spectrum and, in addition to this, there was a significant change in the intensity curve. Determining the end point of the word initial nasals and at the same time the beginning of the following vowel was most complicated in this data. The point in question was located at a place in the spectrum where there were multiple visual cues (intensity curve etc.) indicating a change in the spectrum. It was not always easy to locate such a place but the point at which the most abrupt change occurred in the spectrum was selected to be the end point of the nasals and at the same time the beginning of the first vowel. Therefore, determining the point in question in some of the cases may have been incorrect but as the analyses were systematically executed this is trusted to have no significant effect on the results.

4.5.2.4 Procedure

Infants were tested individually in a sound treated room. They were seated either on a high chair or on their parent's lap[1]. The parent/s of the infant were seated next to the infant in the case when the infants sat on the high chair. One of the parents wore headphones during the experiment except in the cases in which infants were distracted by them and the headphones had to be removed. An integrated tv monitor - video cassette player (Schneider TV/VHS) was placed directly in front of the infant at a distance of approximately 70 cm at eye level. At a distance of approximately 45 cm from the infant a high quality microphone (Sennheiser K3N Studio Kondesator microphone MKH) was attached to the table on which the tv-monitor was placed. The infant was monitored via a Super VHS camera (JVC, GR-S505 Hi-Fi stereo) which was located to the left of the infant at a 45 degree angle. In the adjoining control room the experimenter watched the infant from a tv-monitor. The experiment was recorded both on a video tape (using a Sony DA Pro 4 recorder) and on a digital audio cassette (using a Sony Digital audio tapecorder TCD-D3). In the analyses the DAT tapes were the main source of data but the contextual factors in the experimental situations were also checked from the video tapes.

In the test situation infants were either with one of their parents or with both of them. The parents were told that the aim of the experiment was to get the infant to imitate the woman on the video tape. They were instructed to encourage the infants to imitate in a manner they considered would work with their infants. Some example phrases were provided as examples of what to say as encouragement such as "what did the woman say" and "can you say the same word as the woman"? They were also told to praise the infants in the manner that they usually would with their infants. The only restriction on the verbal encouragement was that the words that the woman said were not to be repeated to the infant. The reason for this was that we wanted to gain data on direct imitations of the same model from all the infants with no interference from other sources. The parents were informed that the test could be interrupted if they wished (if the infant was crying, needed to go to toilet, was inattentive, was hungry etc.) and could be continued later on. All the infants were tested in one session, and the whole video tape material lasted for approximately 5 minutes.

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1 The initial intetion was that the infants would all sit in the high chair but since some of the infants refused to sit in it they were allowed to sit on their parent's lap.

4.5.3 Results and discussion

A total of 153 acceptable imitations were included in the results. There were 76 acceptable imitations in the at risk-group and 77 in the control group. The infant data were first analysed to discover whether the 18-month-old infants were able to distinguish durationally the two quantities of Finnish in an adult-like manner. For this purpose the data of the control infants were investigated. The descriptive statistics of the control infants producing the minimal word pair *mato-matto* are presented in Table 9. It should be noted that in these particular analyses only the data of those individuals who had produced one or both of the minimal pairs employed were included in this study. This was done in order to get more reliable information on the fact whether these infants were able to distinguish the two word structures in their speech.

The control infants' data were submitted to a t-test (for paired samples). As the table shows these infants made a significant difference (which almost reached a highly significant level) in durations of the word medial consonants between the two word structures. Also in producing the word final vowel they made almost a significant difference between the word structures. Both of these differences showed similar tendencies to those produced by the adult speakers[1]. Proportionally the same segments (C2 and V2) were produced with a highly significant durational difference. These results are in accordance with the adult results, except that the adults differentiated statistically significantly also the durations of the word initial consonant and the first vowel. As a curiosity, it should be noted that unlike in the adult data the two word structures did not differ statistically on average in the total durations. It seems by looking at the standard deviations that the distinctions between the two word structures were not consistently executed within these infants. A great deal of variability in the temporal features of the speech has been noted in previous research among infants (de Boysson-Bardies 1986). This kind of variability may well explain the disagreement between the present results and those of the studies of Hurme and Sonninen (1982 & 1985): they data did not indicate that the three and six year old children made a distinction between the durations of the word final vowels in the two word structures. Also the fact that the children in the present study and in those of Hurme and Sonninen were most likely in a different stage of language development (in more of a general rather than imitative) may explain the discrepancy between the results. Furthermore, the difference in the nature of the tasks may have played a part in the results. Nevertheless, the data revealed that in imitations the 18-month-old infants were able to produce on average the quantity distinction in a similar

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1 Meaningful statistical probabilities of the significance of the differences could not be conducted between the imitations and the model since there is only one model to which all the infant data should have been compared. Therefore, an analysis of variance test did not reveal any significant differences between the model productions and the infant productions. Only strikingy different durations between the model and the infant data would have reached a level of statistical significance by the means of statistical tests. Therefore, the infant productions are compared to the adult productions of the same word.

manner to adults. Thus, this entails that infants of this age are already developing the quantity system in their language. The extent and the consistency of quantity manifestations in spontaneous speech is obviously outside of the scope of this experiment. However, the fact that they were able to use durational differences in an adult-like manner in direct imitations gives indications of the developing system.

TABLE 9 Descriptive data of the control infants data in imitating the words *mato* and *matto*.

	Mato			vs	*Matto*			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
/m/: ms	12	47	20	12	52	25	NS
/a/: ms		98	38		100	32	NS
/t/: ms		168	19		352	41	**
/o/: ms		222	85		136	78	*
/m/: %		9	5		9	6	NS
/a/: %		18	7		17	6	NS
/t/: %		32	11		54	6	***
/o/: %		41	13		20	5	***
/o/:/a/		2.6	1.4		1.4	.7	**
/o/:/t/		1.5	.8		2.8	.9	***
total		537	90		640	221	NS

The average imitation data of the pseudowords are presented in Table 10. Interestingly, the control infants imitated these pseudowords more often in comparison to the real Finnish words. The structure of the pseudowords (without an initial consonant) employed here may have been easier for this age infants to manage. In the imitations of the pseudowords the control infant data was relatively comparable to those of the real words. The only points of divergence between the pseudoword and real word data were in the durations of word final vowels, in the proportional durations of vowels preceding the word medial consonants, in the syntagmatic relation between /V1/ and /V2/ and in the total durations of the words. The tendencies in all these cases were, however, similar between the two types of productions and therefore these differences are not significant. It seems that these infants had developed a system of making quantity distinctions in their speech to the extent that it could also be utilised in an adult-like manner in novel exemplars, i.e., in pseudowords.

TABLE 10 Descriptive data of the control infants data in imitating the pseudowords *ata* and *atta*.

Parameters	*n*	Ata *Mean*	Ata *SD*	vs	*n*	Atta *Mean*	Atta *SD*	*Sig.*
/a1/: ms	17	111	58		17	107	39	NS
/t/: ms		137	59			310	163	***
/a2/: ms		177	83			138	49	NS
/a1/: %		26	8			20	6	*
/t/: %		33	9			54	12	***
/a2/: %		41	12			26	9	***
/a2/:/a1/		2	1.4			1.5	.9	NS
/a2/:/t/		1.5	2.5			1.0	1.3	*
total		410	162			556	190	*

The high genetic risk for dyslexia infants' imitation data involving the words and the pseudowords are presented in Tables 11 and 12. These tables demonstrate that first of all the amount of the imitations did not differ significantly between the words and the pseudowords. This entails that the pseudowords did not pose any noticable problems as such to the GR+ infants.

Table 11 shows that GR+ infants did not use duration to differentiate CVCV and CVCCV structure words as clearly as did the control infants and the control adults. Durationally they did differentiate between the word medial consonants in the *mato* and *matto* words virtually as distinctly as the other infants but proportional differences did not reach a highly significant level which they did in the GR- infants data. A noticeable difference between the two subject groups' data was also in the so called secondary cue for the quantity distinction between the two word structures. The relationship between the word final vowels in the CVCV and CVCCV structures showed similar tendencies to that of the GR- infants but neither durational differences nor proportional differences reached a highly significant level in the GR+ data. The only durational relation in which there was a highly significant difference between these CVCV and CVCCV structure words was in the syntagmatic relation between the word final vowel and the word medial consonant.

TABLE 11 The data and relation of the average *mato* and *matto* imitations produced by the GR+ infants.

		Mato		vs	*Matto*		
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
/m/: ms	16	48	27	16	69	36	NS
/a/: ms		122	50		120	30	NS
/t/: ms		198	128		322	98	**
/o/: ms		209	106		195	110	NS
/m/: %		9	5		10	4	NS
/a/: %		22	8		17	5	*
/t/: %		34	16		46	8	*
/o/: %		35	12		27	8	*
/o/: /a/		1.4	.7		1.1	.4	NS
/o/:/t/		1.1	.5		3.9	1.2	***
total		588	143		709	195	NS

The results of the pseudoword imitations by the GR+ infants were even more striking. As Table 12 demonstrates these infants did not use clear durational differences to make the distinction between the two word structures in any of the segments with the exception of the word initial vowel. These results are significantly different to those of the GR- infants. They suggest that the infants with a high genetic risk for dyslexia may indeed be unable to use durational cues, both primary and secondary, for quantity oppositions especially in producing new words. Since standard deviations were greater in comparison to the GR- infants it seems that there is even more variability in the data than there was in the data of the GR- infants. As a group, however, the GR+ infants' data differs remarkably from those of the GR- infants.

TABLE 12 The data and relation of the average *mato* and *matto* imitations produced by the GR+ infants..

		Ata		vs	*Atta*		
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
/a1/: ms	14	104	34	14	138	44	*
/t/: ms		233	170		264	137	NS
/a2/: ms		171	60		184	59	NS
/a1/: %		22	9		24	7	NS
/t/: %		42	18		44	15	NS
/a2/: %		35	13		32	9	NS
/a2/:/a1/		1.9	1.1		1.4	.3	NS
/a2/:/t/		1.1	.8		1.6	1.1	NS
total		507	159		585	142	NS

Since the variability of the infant data was clearly evident analyses were also executed on the bases of individual performances. These analyses included also the data of those individuals who did not imitate both members of the minimal pairs. They were included in order to gain as much information of the durational aspects of imitations as possible in both of the subject groups. Individual imitations were converted into z-scores in relation to mean and standard deviation of the model words in each variable. In addition to the statistical analyses, the judgments of the clear deviances from the intended structures were made on the basis of listening to the words. The results of the statistical analyses and those based on the perceived impressions were identical in indicating which productions were clearly deviant from adult models (the z-score data are shown in Table 21 in Appendix 2). The results demonstrated that there were only four out of 19 GR+ infants who produced *matto* instead of *mato* and the respective figure was three out of 17 in the GR- infants. The imitation data of the *matto* word indicated that even fewer infants produced *mato* when intending to produce *matto*: four out of 19 of the GR+ infants and one out of 20 infants in the GR- group. Similarly to the group data, the individual data shows that the real Finnish words did not cause difficulties to these infants in general.

The individual pseudoword imitations proved to be more variable than the real word imitations. In the GR+ group as many as 9 infants out of 21 produced *atta* when required to produce *ata*. In the GR- group the respective figures were two out of 21. Thus, the difference in variability within the subject groups was remarkable. There was also variability in the imitations of the *atta* word, but to a slightly lesser extent. In the GR+ group seven of the 18 infants who imitated the *atta* word produced the *ata* word. In the GR- group three out of 25 infants produced *ata* when required to produce the *atta* word. These results show that the pseudowords caused significantly more problems to the GR+ infants than to the GR- infants. Again, these results suggest that these GR+ infants had problems utilising temporal features in speech productions when they did not have a representation of a word.

The imitation data of the two subject groups were also submitted to an analysis of variance in order to compare the imitations of the two subject groups. First of all it should be noted that none of the response times between the two subject groups differed significantly. The response times are shown in Tables 13-16 (named as "distance"). These findings are in accordance with the earlier findings of Brady et al. 1989. This results suggest that there is no difference in the spoken responses as far as the response time is concerned between dyslexics and nondyslexics. This finding supports general observations that dyslexics do not seem to be significantly slower in producing words than nondyslexics.

The productions of the *mato* word in the two subject groups were similar with no statistical differences between the performances. Table 13 demostrates these results. Only the syntagmatic relation between the word final vowel and the word medial consonant was statistically different between the two subject groups, with the GR- infants having a larger differences between the two segments similarly to the adults.

Although the statistical analyses did not reveal any statistical differences in the *mato*-productions between the two subject groups, the results show that the GR- infants productions tend to be closer to the adult models in comparison to the GR+ infants. The word medial consonant was clearly shorter in duration than the following vowel in the productions of the control infants whereas the GR+ infants did not differentiate these sounds in the durations. Thus, the most critical cues for the quantity degree of CVCV structure word seem to be produced by the control infants more in the way the adults do it in comparison to the GR+ infants. These results could also indicate that the GR+ infants may be able to produce the most important cue for the distinction in question but fail to produce the secondary cue in an adult-like manner. Interestingly, the adult data indicated similar tendencies between the dyslexic adults and the control adults.

TABLE 13 The *mato* word imitations by the GR- and GR+ infants.

	Control Infants			Risk Infants			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
mato:/m/:ms	17	51	21	19	44	27	NS
mato: /a/:ms		95	37		120	47	NS
mato: /t:/ms		155	64		187	120	NS
mato: /o/: ms		206	91		191	106	NS
mato: /m/:%		10	5		9	5	NS
mato: /a/:%		19	7		23	8	NS
mato: /t/:%		31	11		34	15	NS
mato: /o/:%		40	13		34	12	NS
o/a		2.5	1.3		1.7	.8	*
o/t		1.6	.8		1.4	.2	NS
total: ms		508	116		552	155	NS
distance: ms		2224	2127		2381	1397	NS

The *matto* word production data are presented in Table 14. These results yielded significant differences in the proportional durations of the word medial consonant and that of the word final consonant. Also the syntagmatic relationship of the two segments reached a statistically significant level. Again the productions of the GR- infants showed once more the same tendencies as those of the adults whereas the GR+ infant's productions were durationally further away from the adult productions.

TABLE 14 The *matto* word imitations by the GR- and GR+ infants.

	Control Infants			Risk Infants			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
matto:/m/:ms	19	52	23	19	62	37	NS
matto: /a/:ms		102	35		110	37	NS
matto: /t:/ms		339	161		300	106	NS
matto: /o/: ms		136	72		183	104	NS
matto: /m/:%		9	5		9	4	NS
matto: /a/:%		18	7		17	5	NS
matto: /t/:%		52	9		46	8	*
matto: /o/:%		21	5		28	8	**
o/a		1.5	.8		1.8	1.0	NS
t/o		2.7	.9		1.8	.7	*
total: ms		629	232		658	217	NS
distance: ms		2011	881		2251	1161	NS

The productions of the *ata* word between the two subject groups differed statistically only in the durations and proportional durations of the word medial consonant as well as in the total durations of the words. A descriptive presentation of these data is given in Table 15. The fact that the word medial consonant was shorter and closer to model production[1] together with the relationship with the longer word final vowel made the imitations of the control infants as a group closer to the adult model in comparison to the high genetic risk for dyslexia infants.

TABLE 15 Descriptive data of the productions of the pseudoword *ata* in the GR- and the GR+ infants.

	Control Infants			Risk Infants			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
ata: /a1/:ms	21	112	53	21	114	57	NS
ata: /t/:ms		128	57		223	164	*
ata: /a2/:ms		178	81		183	81	NS
ata: /a1/:%		27	9		23	11	NS
ata: /t/:%		31	10		40	17	*
ata: /a2/:%		42	12		36	13	NS
a2/a1		1.9	1.3		1.9	1.0	NS
a2/t		1.6	1.0		1.2	.8	NS
total		407	148		521	197	*
distance: ms		1979	1485		2976	1802	NS

1 The data on the model productions are shown in Table 22 in Appendix 3.

The imitations of the pseudoword *atta* were more divergent between the two subject groups. Here the most significant difference was in the duration and proportional duration of the word final vowel, with the GR+ infants having considerably longer duration in that vowel. Furthermore, there was a difference between the word medial consonant, with the GR- having a longer duration in that segment. Importantly, the syntagmatic relation between the consonant and word final vowel was also more distinct in the control infants making the quantity distinction more significant. Similarly to the *ata* word, this word was produced temporally by the GR- infants more in the manner of the adults.

TABLE 16 Descriptive data of the productions of the pseudoword *atta* in the GR- and the GR+ infants.

	Control Infants			Risk Infants			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
atta:/a1/:ms	25	112	41	18	138	40	*
atta: /t/:ms		302	144		267	140	NS
atta:/a2/:ms		135	49		186	54	**
atta:/a1/:ms		21	8		24	7	NS
atta: /t/:ms		53	12		44	15	*
atta:/a2/:ms		25	8		32	9	**
a2/a1		1.4	.8		1.4	.3	NS
t/a2		2.4	1.2		1.6	1.0	*
total: ms		550	171		591	140	NS
distance: ms		2881	1635		2039	1534	NS

In general, it appears that the productions of the two subject groups differed in the proportional durations of the primary cue and the secondary cue of the quantity distinction as well as in their relation. As a group the control infants showed a tendency of being able to use the temporal information of the segments similarly to the adults whereas the high genetic risk infants were further away from the adult targets.

The same data were also analysed to determine whether there was a difference between the imitations of the boy infants and those of the girl infants. These analyses were done in order to ascertain whether dividing the subjects into other groups than according to a dyslexia risk would give similar results than had been gained so far. ANOVAs demonstrated that the durational features in none of the parameters were significantly different between the boy and the girl infants (These data are shown in Table 23-26 in Appendix 3). These results clearly demonstrate that in this experiment the gender of the subjects did not affect the way the temporal aspects of the words were produced. In fact, there is no evidence which indicates that gender as such affects the way in which durations are used in speech sounds.

The infant imitation data were further compared to the adult production data within the two subject groups in order to see if there was a relationship between the adult models of the families and the productions of the infants. First, the data of the control group infants and parents are compared. These data are presented in Tables 17 and 18. The differences in the *mato* productions are virtually non-existent between the control parents and their infants. However, there was almost a statistically significant difference in the durations of the word medial consonant between the adults and the infants with the infants having a longer duration in that segment. It should be noted that the absolute durations in general were longer in the infant productions. This was expected on the basis of previous research which has indicated that the infants productions are generally longer in duration in comparison to the adults' productions (e.g., Hurme & Sonninen 1982, 1985).

In the proportional measures, which can be considered to give more reliable information on the actual temporal aspects taking into account the different speech tempos, there was also only one segment in which the durations of the adults and the infants differed: the adults had a longer duration than the infants in the word initial consonant. As was mentioned earlier, the segmentational aspects as well as the aspects of quality n the infant productions specifically in this word initial nasal were considerably more fuzzy in comparison to the adult data. These factors are believed to be the cause for the aforementioned difference in the results.

TABLE 17 Descriptive data for the *mato* word productions in the control infants and adults.

	Control Adults			Control Infants			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
mato:/m/:ms	8	66	30	8	51	21	NS
mato: /a/:ms		84	41		95	37	NS
mato: /t:/ms		118	28		155	34	**
mato: /o/: ms		168	74		206	91	NS
mato: /m/:%		15	5		10	5	**
mato: /a/:%		19	5		19	7	NS
mato: /t/:%		28	7		31	11	NS
mato: /o/:%		38	9		40	13	NS
o/a		2.2	1.2		2.5	1.3	NS
o/t		1.5	.7		1.6	.8	NS
total: ms		436	130		508	116	NS

In the *matto* word there were statistically significant differences between the control infants and their parents. The data are presented in Table 18. Most significantly the differences were found in the proportional durations of the word final vowels. It appears that while the infants were able to have an adequate duration for the primary cue of the CVCCV structure word they were unable to shorten the final vowel according to the adult model.

TABLE 18 Descriptive data for the *matto* word productions in the control infants and adults.

	Control Adults			Control Infants			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
matto:/m/:ms	9	67	26	9	52	23	NS
matto: /a/:ms		87	20		102	35	*
matto: /t:/ms		319	95		339	161	NS
matto:/o/: ms		88	24		136	72	**
matto: /m/:%		12	4		9	5	*
matto: /a/:%		16	3		18	7	NS
matto: /t/:%		56	8		52	9	NS
matto: /o/:%		16	4		21	5	***
o/a		1.0	.8		1.5	.8	**
t/o		3.9	1.7		2.7	.9	**
total: ms		560	125		629	232	NS

The dyslexics parents and their infants' production data are presented in Table 19 and 20. As in the control group families, here too the infants' durations measured in milliseconds were relatively longer than those of their parents. Previous research has observed that there is a clear decrease in segment durations as well as less variability with increase of age (Tingley & Allen 1975, Chermak & Schneiderman 1986, Smith 1978 and 1992). The general causes for the temporal development in productions have been attributed to underdeveloped neuromuscular control, or to the amount of experience with the speech production processes, or to a combination of both. Whatever the cause is behind this factor, it is clear that temporal control over the durations of speech segments develops during childhood.

Similarly to the control families, also the dyslexic parents and their infants seemed to produce the *mato* word in a relatively similar manner. In the absolute measures there was almost a statistical difference in /V1/ as well as a statistical difference in the durations of /V2/. In both of these cases the infants had longer segmental durations than the adults. Only the proportional duration of the word initial consonant was durationally clearly significantly different between the productions of the dyslexic parents and their infants with the infants having a shorter duration in that segment. As was mentioned earlier this could be due to segmentation problems. Also the fact that the quality of the particular consonant in the initial position of the word was not necessarily the same between the productions of the adults and the infants may have caused this result.

The CVCCV structure word proved to be more difficult for the infants and therefore the differences between the parents and the infants are greatest in the *matto* word in most of the parameters. The tendency was the same as in the control infants that the GR+ infants made a relatively short word medial consonant and long final vowel. Here the GR+ infants were even further away than the GR- infants from their parents' productions. It appears that especially the relative shortness of the word final vowel in the CVCCV structure as well as the length of the word medial consonant were difficult to control for the GR+ infants.

TABLE 19 Descriptive data for the *mato* word productions in the dyslexic adults and their infants.

	Dyslexic Adults			*Risk Infants*			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
mato: /m/:ms	11	75	32	11	44	27	**
mato: /a/:ms		101	33		120	47	NS
mato: /t:/ms		132	37		187	120	*
mato: /o/: ms		140	70		191	106	NS
mato: /m/:%		17	6		9	5	***
mato: /a/:%		23	6		23	8	NS
mato: /t/:%		30	8		34	15	NS
mato: /o/:%		30	11		34	12	NS
mato:/o/÷/a/		1.5	.7		1.7	.8	NS
mato: /o/ ÷/t/		1.1	.5		1.4	1.2	NS
total: ms		448	109		552	155	*

TABLE 20 Descriptive data for the *matto* word productions in the dyslexic adults and their infants.

	Dyslexic Adults			Risk Infants			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
matto: /m/:ms	10	81	34	10	62	37	NS
matto: /a/:ms		92	29		110	37	NS
matto: /t:/ms		357	80		300	106	NS
matto: /o/: ms		93	30		183	104	***
matto: /m/:%		13	5		9	4	**
matto: /a/:%		15	4		17	5	NS
matto: /t/:%		57	7		46	8	***
matto: /o/:%		15	4		28	8	***
matto:/o/ ÷ /a/		1.1	.4		1.8	1.0	**
matto: /o/ ÷/t/		4.2	1.6		1.8	.7	***
total: ms		623	129		658	217	NS

The average proportional durations of the adults' and the infants' productions are also presented graphically in Figures 37 and 38. Figure 37 demonstrates interestingly that the segment durations in the *mato* word between the dyslexic adults and the GR+ infants as well as those of the control groups' adults and infants show similar tendencies. In other words, the GR+ infants seemed to have produced similar durations in their *mato* words to the dyslexic adults, and similar relationship was evident between the control groups. Similar relationship but not as clearly can also be seen in Figure 38 in which the durations of the *matto* word are graphically shown. Here there seems to be a relationship between the control infants and the control adults but this kind of relationship is not evident between the dyslexia groups. These observations could be interpreted as showing that there is a link between the productions of the parents and their infants. Since speech communication is by nature social it is believed that the parental input has an effect on infants' speech. The questions whether the suggested relationship between parents and infants is due to some biological factor about muscular control or perceptual categorisation skills or both, or whether this relationship is due to the fact that parents provide a strong model for infants of this age in the communication situation and the interaction or negotiation of some aspects of speech like temporality evolves in the particular social contact between parents and infants, or whether both genetic and social aspects affect the proposed relationship remains to be answered in future research.

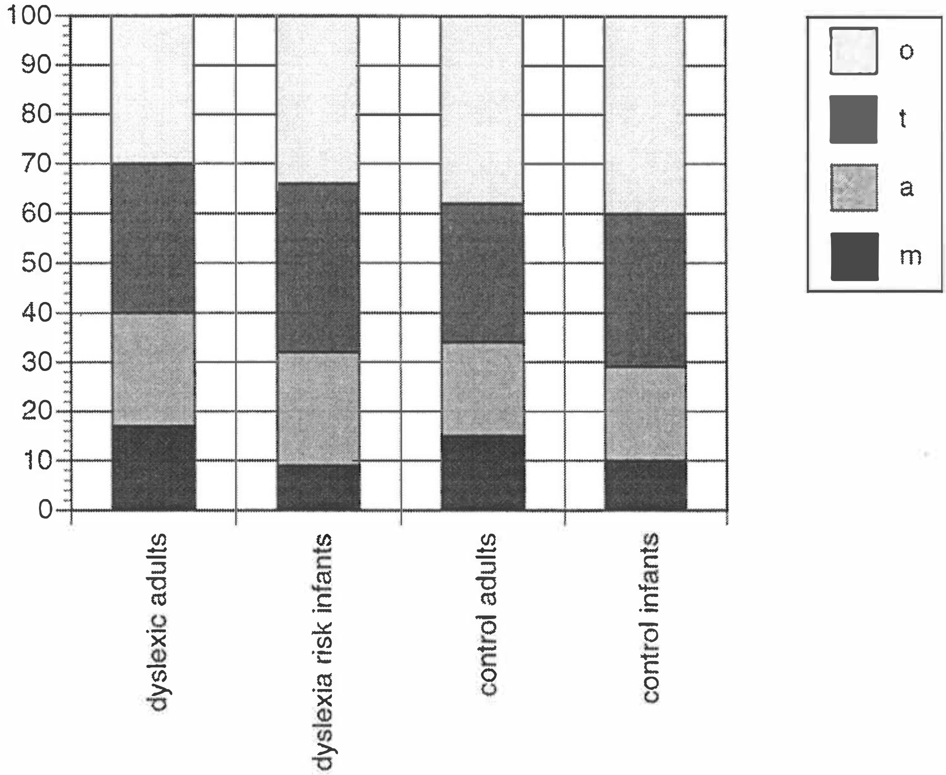

FIGURE 37 A graphical presentation of the proportional durations of the *mato* word within the dyslexia and the control families subjects. The graphs indicate that the productions of the parents and infants from the same families produced the mato word similarly.

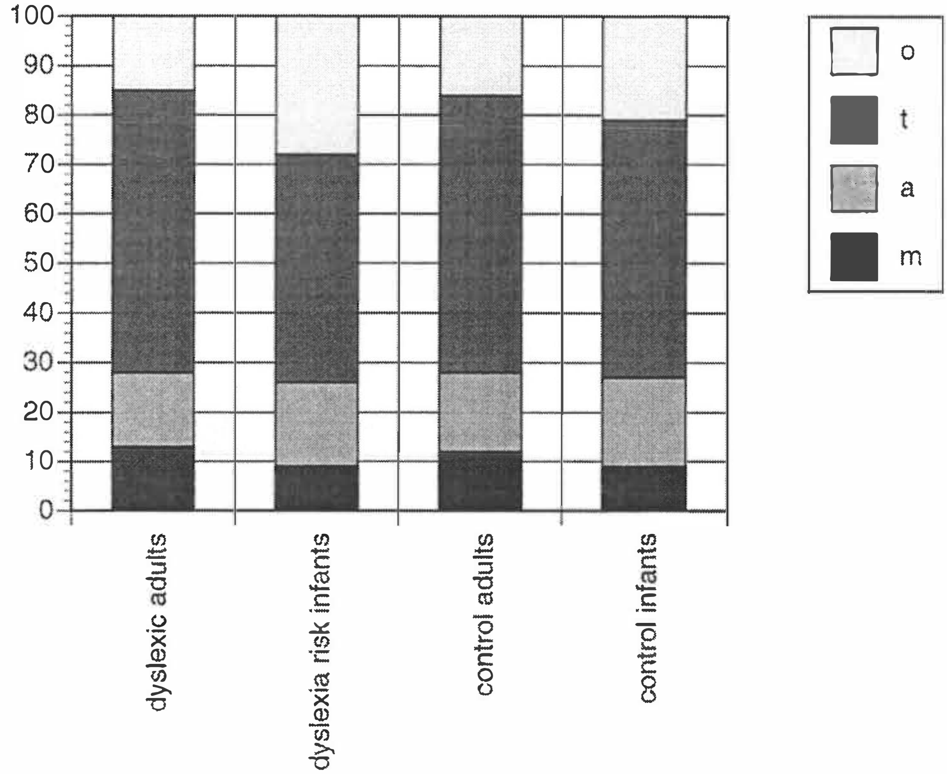

FIGURE 38 A graphical presentation of the proportional durations of the *matto* word within the dyslexia and the control families subjects. The graphs shows that the durationally the productions within the control group subjects are similar but there is no clear resemblance durationally in the matto words produced by the subjects of the dyslexia group.

4.6 Conclusion

In conclusion, the results of the infant imitation experiment showed several main tendencies. First, although the absolute durations were relatively longer in the infants productions in comparison to those of the adults, proportionally 18-month-old infants were able to imitate the temporal aspects of the quantity distinction in a similar manner to the adults. Variance within the infants was great, however, which partly caused the significant differences between the infant and the adult productions. The main points of difference were the proportional durations of the word final vowels in the CVCV structures and those in the CVCCV structures. This may be caused by the fact that the end of the words tend to lengthen in infant productions, and these infants had not yet developed adequate control over their muscular control which would enable them to use the durational feature more distinctively also in the final position of the words. Although there was a clear trend of relatively long word final vowels, the individual data demonstrated that there were many infants who were able to use also the secondary cue in the quantity distinction of the CVCV/CVCCV structures. Thus, at this age some of the infants were able to produce the quantity distinction of Finnish at least in their imitations.

As to the dyslexia aspect, the GR+ infants productions did differ durationally from those of the GR- infants and their corresponding parents. This result confirmed the hypothesis of this experiment. The GR+ infants had even more difficulties than the GR- infants in using the durational cues of the quantity distinction appropriately according to the Finnish language. The GR+ infants encountered especially significant difficulties in producing the durational relationships of the segments in pseudowords. This result strongly suggests that the high genetic risk for dyslexia infants were not able to generalise the use of temporality in producing new words. These results could also be interpreted as meaning that they were unable to hear the temporal cues of the model productions or that they did not pay attention to them. Also the possibility that all of these factors played a part in the GR+ infants data.

The fact that there seemed to be a tendency for the infant productions to model those of their parents could be significant. This could entail that the parental model which the young infants are surrounded by most of the time during the fundamental stages of language development may have a strong influence on the way in which the infants learn to use duration distinctively in speech. Thus, if dyslexia is genetically transmitted, as it seems to be, it could also be that the behavioral models of the environment enhance the differences even further?

But before drawing any final conclusions it should be remembered that the data from both the infant and adult production experiments were limited in size in terms of the employed words and the amount of productions. More thorough and systematic research is needed in order to verify the tendencies of the present study. Also the fact that neither the infant productions or the adult productions were studied from spontaneous speech can be seen as a limitation to the data. Imitation experiments have been continuously critisised on the grounds for the possibility that they may not provide information on the speech abilities of children but rather on the ability to mimic adult productions. It is considered here, however, that the information gained from imitation experiments should as such reflect something of children's speech abilities and cannot be disregarded.

5 INTEGRATION OF EVIDENCE FROM THE PERCEPTION AND PRODUCTION EXPERIMENTS IN LIGHT OF DYSLEXIA

In this section some general issues concerning the dyslexia experiments of this study are discussed. The aim of the discussion is twofold: Firstly, an attempt is made to link together the information gained from the separate experiments. Secondly, certain factors pertaining to the experiments are discussed and suggestions for future research are given.

The main purpose of the dyslexia experiments here was to elucidate with experimental evidence the currently hotly debated issue on temporal processing in dyslexia. The perception experiments demonstrated that dyslexia may involve difficulty in perceiving temporal cues of speech sounds with short durations. This evidence supports the suggestion of Tallal (1980) according to which dyslexics have problems in dealing with the brief temporal information of auditorily presented signals. But as was demonstrated with the adult experiment there was clear variability in the performance within the dyslexics. It seems that if dyslexics have deficiencies in perceiving durational information only some of them have clear problems with it and most of them have less noticeable difficulties. In the infant experiment in which only the performance on the group level could be investigated the differences between the subject groups were the most prominent. Interestingly, preliminary findings of another member of the dyslexia project Paavo Leppänen (Leppänen & Lyytinen 1997), who has investigated the same 6 month old infants employing stimuli from the same *ata*-continuum with an ERP method, are affirmative of the temporal processing deficiency in these infants with a high genetic risk for dyslexia. Thus it appears that we may have found an early precursor for dyslexia in a form a temporal processing deficiency. As was mentioned in Chapter 3 developmental aspects may also explain the differences between the groups at least partly. The developmental aspect will be investigated further with the same children in perception and production experiments when they are 5,5 years old. Then also individual level performances will be investigated. However, the adult experiments indicated that it is likely that there are dyslexics with different types of deficits or with a different mixture of underlying deficits, and one of these deficits is a temporal processing deficiency.

The production experiments indicated that also the productions of the dyslexia group subjects differed with respect to some aspects of the durational composition of words and pseudowords. Particularly the secondary durational cue (i.e., the duration of V2) for the distinction between CVCV and CVCCV structures seemed to differentiate the dyslexics from the controls although the infant data showed that also the primary cue for the distinction was differently produced by the GR+ infants. The results of the imitation experiment could also be interpreted as showing that the GR+ infants had difficulties with the temporality of the whole word patterns. It should be noted that the imitation experiment included the perception of sounds as well as production since the stimuli had to be perceived in order to know what to produce. Therefore, the indications of the production experiments are not surprising since it is believed here that there is a connection between production and perception sides of communication.

There may be some kind of timing program which affects both the production and perception of speech sounds as well as all the other activities involving timing. In fact, the influential theories involving temporality which were proposed by Kozhevnikov and Chistovich (1966) and Lindblom(1963) suggested that people have some kind of rhythm generators or timing programs whose job is to indicate and instruct the timing of different units in relation to other units. This line of thought is interesting in that it presupposes that the timing program included in us is biologically determined, and since we are dealing with familial dyslexia it could be that the timing device is somehow "off time" or slow in dyslexics. If this is the case then it is plausible that the experiments here involving duration illuminated early signs of dyslexia already in the young infants.

The perception experiment demonstrated that dyslexics or some of them have problems with categorisation of sounds with varying duration. Previous research has also observed categorisation difficulties in dyslexics (e.g., Godfrey et al. 1981, Werker et al. 1987, De Weirdt 1988). It has been suggested that the fuzzy representations of speech sounds underlie categorisation problems in dyslexics (Godfrey et al. 1981, Werker et al. 1987, Elbro 1990). The results of the present study seem to support the assertion that the problems with categorisation and representations in some dyslexics are due to indistinct perception of durational information. It should be noted that the perception studies in which categorisation problems have been observed employed syllables comprising of stop consonants and vowels as stimuli. Although in those studies (Godfrey et al. 1981, Werker et al. 1987, De Weirdt 1988) durational features of the stops were not altered in the constructions of the stimuli it is plausible that an intrinsic part of the nature of stops is their brief temporal information (i.e. in the form of rapid transitions). This entails that the categorisation problems of dyslexics observed in those studies may also have involved deficits in processing brief temporal information. Clearly there is a need to study categorisation abilities of dyslexics employing other stimuli than stops in order to elucidate the possible problem of categorisation in dyslexics.

If it is assumed that dyslexics have difficulties creating accurate representations of phonological information then what is/are the underlying deficits of this difficulty? Could it be that some kind of deficiency in the auditory memory lies behind the representation problem? There are several studies on dyslexia which have proposed that dyslexics have difficulties with short-term memory for phonological information (e.g., Shankweiler et al. 1979, Mann et al. 1980, Brady et al. 1983). The perception tasks here involved the memory skills of the subjects as well as perceptual abilities, as do all perception experiments. The perception experiments of the present study can be considered to be low in terms of memory load since the standard stimuli *ata* were repeated many times during the testing. However, stimuli other than the standard stimuli were presented only four times on four different occasions. It could be that the exposure time for the stimuli were too short for the dyslexia group subjects to create or/and retrieve appropriate representations of the stimuli. In the adult perception experiment the results on the response time data indicated that dyslexics were slower than nondyslexics in creating representations of the stimuli. The results could be interpreted as showing also that if the dyslexics were uncertain of the stimuli the extra time it took for them to respond was the time it took to decide which of the alternatives the stimuli was. In the imitation task the response times were also measured but there were no differences in these times between the infants of the two subject groups. The difference between the results in the perception and production experiments could be explained by the argument that since the perception test was more demanding because of the artificiality of the stimuli (with the slight durational variations) underlying differences between dyslexics and controls surfaced in these demanding conditions.

A memory load was also attached to the imitation experiment (more in the form of short term memory for the pseudowords and also the long term memory for the words) since the stimuli to be imitated were repeated only twice (although on three different occasions). The adults' production task involved phonological representations which had to be retrieved from long term memory. Since the GR+ infants had more difficulties with imitating the durational features of the pseudowords than those of the real words it could be that they may have some kind of short-term memory deficiency for durational information. However, since in the perception experiment the performance of the dyslexia group subjects was similar to that of the control group subjects with the stimuli with longest durations but was further away in perceiving stimuli with shorter durations this must entail that the memory alone cannot explain the results.

Or could the fuzzy representations of dyslexics be caused by difficulties with phonetic perception per se? Previous studies which have involved verbal stimuli have indicated that dyslexics do not differ from nondyslexics in perceiving all speech stimuli. For example Steffens et al. (1992) used vowels as stimuli and did not find any deviations in the performance of dyslexics in this tasks. Most studies which have found that dyslexics have difficulties with speech stimuli have used syllables involving stop consonants and vowels. As was mentioned, the nature of stop sounds may be particularly demanding for dyslexics since the crucial cues for the quality of the sounds occur briefly in the transitions. Since the quality of the speech sounds did not play a decisive role in the perception tasks of the present study it seems unlikely that purely the phonetic nature of the stimuli without the durational aspect would have caused the results here.

Speech sounds are made up of acoustical components which are also the components of nonverbal sounds. Could it be that the observed differences in the performances of the dyslexia groups and the control groups were due to some basic auditory perception deficiency? Tallal (1980) has suggested that dyslexics may have problems with auditory perception of brief temporal information which also underlie their deficiencies with phonetic information. She draws this conclusion mainly on the basis of her findings in which dyslexics children deviated from controls in perceiving tones with short interstimulus intervals in TOJ tasks. As was noted earlier in Chapter 3 there were several factors which may have caused these findings, one of them being the memory factor involved in the tasks. Here the parameter durational cue of the stimuli in a form of silence could be seen as a purely physical acoustical feature, and thus there may be a temptation to conclude that these results prove Tallal's assumption right. However, since silence is a natural and intrinsic part of unvoiced stop sounds, these results cannot be viewed as showing that the differences were caused by dyslexics' deficiencies with purely acoustical auditory information. In the future dyslexics' ability to perceive durational differences of tones or other nonverbal stimuli would have to be specifically investigated in order to find out whether the proposed temporal deficiency of some dyslexics is connected to speech sounds or whether it is due to some basic auditory temporal processing deficiency. This aspect will be investigated in the near future in the perception experiments of the dyslexia projects to which the present study belongs.

As was mentioned, the deviancies of many of the dyslexics here were only subtle. It is conceivable that the possible temporal processing difficulty of dyslexics is highlighted in experiments using manipulated stimuli, the type of stimulus that does not exist in real life communication. If dyslexics had more gross problems with the perception of duration then this deficiency would be more evident in their spoken communication. Speech is interwoven in temporality and there are a substantial amount of duration cues which play an intrinsic part in distinguishing sounds from other sounds. If dyslexics had serious problems with temporality communicating with them would be noticeably hindered but as anyone who has communicated with dyslexics or is dyslexic him/herself knows this is clearly not the case. Other researchers have also suggested that the possible perceptual difficulties of dyslexics are subtle (e.g., Shankweiler et al. 1979, Werker et al. 1987). The proposed subtleness of the deficiency in perceiving durational information could be seen to entail that if the stimuli had been more complex in terms of the phonotax and the length of words the differences between the dyslexics and the controls would have been even greater. Now the nature of the stimuli facilitated the subjects' focusing on the primary cue of VCV and VCCV structures. The stimuli employed in this study were simple mainly due to the fact that the same stimuli were used in the experiments with the infants.

It seems that the difference between the performances of the dyslexia group subjects and the control subjects in the perception experiments were due to a difference in categorising and representing temporal information of the speech stimuli. This difference was most evident in the category boundary between the short and long quantity degrees. Repp (1984, 320) states an interesting factor concerning the categorical perception paradigm. He claims that in experiments like the ones employed in the present study the category boundaries become overemphasised at the expense of categories, which in fact have the most important functions in speech. In other words, in communication the artificial boundaries, which have been located in perception experiments by changing only one acoustical parameter, do not exist. Therefore, one might wonder if there is any linguistic significance in finding out that dyslexics have problems with stimuli located at or near the boundary. Also does it have any linguistic meaning that the production experiments indicated that dyslexics may have difficulties especially with the secondary cue of the quantity distinction in (C)VCV and (C)VCCV structures? Could it be that although the dyslexics here had problems in categorising stimuli according to durational cues that other cues for quantity degree such as the spectral information, the linguistic context, etc. would facilitate them in perceiving and thus producing the quantity degrees appropriately? At this point it should be remembered again that although duration has a crucial role in quantity distinction in Finnish other acoustical features such as fundamental frequency may have a role in that distinction. Redundancy in linguistic elements is noticeable. Thus, the role of multiple cues in language and speech is not denied here. It is likely that since the quantity degrees are usually kept apart durationally in clear fashion dyslexics would not have problems in perceiving and categorising speech sounds into two quantity categories. However, since there is great variation in speech sound durations within and between speakers in order to create stable and distinct representation of short and long quantity categories dyslexics may need more exposure to linguistic stimuli than nondyslexics. In addition, although children who start to learn to read and write have been exposed to language for quite a while the language and certain contextual features of it are not as developed as they are later on in young children.

The importance of acquired representations in the early stages of the demanding task of learning to read in which one has to decode printed words and transform them into phonological representations is highlighted. And if the beginning of this task is already burdened with indistinct representations then the matching of abstract visual symbols to these fuzzy phonological representations may significantly hinder the task of learning to read. The fact that speech is highly complex and the alphabet is only an abstraction of it often without visible markings of the durational aspects, does not make the task of learning to read easy for persons who have poor temporal representations of speech sounds. In the Finnish language we do mark visibly certain durational aspects also in the printed text like the relatively long duration of the word medial consonant in CVCCV structure. However, not all the durational cues are visible in writing. The relatively long duration of the word final vowel in CVCV structure is an example of this. It seems that in writing as well as in speech the understanding of the proportional significance of durational cues is one of the key factors in dealing with language. Large items such as words or phrases form the reference points to which individual sound durations are normally compared. And since in speech there may be multiple durational cues for one linguistic distinction as is the case in the stimuli employed in the present study the demanding task of dealing with them without confusing them may be difficult for those who have subtle difficulties in dealing with durational information.

The experiments of the present study revealed interesting factors about the perception and production of durational features of speech in dyslexics. The results strongly suggest that dyslexics may have a temporal processing deficiency in perceiving speech sounds and this deficiency may be reflected also onto the durational aspects of productions. Perhaps even more important finding concern the infants. The experimental evidence here showed remarkable differences between the 6 month old infants with a high genetic risk for dyslexia and those with no such risk in perceiving speech sounds with varying durations. The GR+ infants needed a longer duration of sound in comparison to GR- infants in order to categorise it as having the long quantity degree. Thus, the results suggest that a temporal processing deficiency may be an early precursor for dyslexia. If this is the case then this finding will be useful in the future in diagnosing dyslexia in young children and in the designs of intervention programs. Obviously the temporality aspect in dyslexia cannot be dealt with in its entirety in a single study. This study dealt with limited linguistic material but the results as such were striking and showed that the temporality aspect should be studied further in the future.

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Appendix 1

Individual data on the points in the categorisation function curves in which 10, 50 and 90 percent of the estimated responses would be *atta*-responses. The width of the phoneme boundary is indicated in the right column.

Dyslexic adults:

P10	P50	P90	bandwidth
1,30	2,60	4,90	3,60
1,30	2,30	4,10	2,80
2,50	4,00	7,80	5,30
2,70	4,00	5,30	2,60
2,60	3,90	7,80	5,20
2,00	3,50	5,00	3,00
3,10	4,60	7,80	4,70
1,60	4,60	7,20	5,60
1,80	3,20	4,70	2,90
2,20	3,50	4,90	2,70
2,20	3,70	5,20	3,00
1,10	2,00	4,10	3,00
1,30	3,00	5,40	4,10
1,50	3,00	6,70	5,20
1,70	3,30	5,30	3,60
2,30	4,10	5,90	3,60
2,20	3,50	4,90	2,70
1,20	2,00	3,40	2,20
1,60	2,90	4,50	2,90
1,20	2,00	3,40	2,20
2,00	3,50	5,00	3,00
1,40	2,50	4,20	2,80
1,50	2,80	4,60	3,10
1,10	1,80	3,00	1,90
1,20	2,00	3,40	2,20
,00	4,20	5,70	5,70
1,40	2,50	4,20	2,80
2,00	3,80	5,50	3,50
1,10	1,80	3,00	1,90
,90	1,50	2,30	1,40
1,80	3,20	4,70	2,90
1,40	2,50	4,20	2,80
1,40	2,50	4,20	2,80
2,50	4,30	6,20	3,70
1,60	3,50	6,00	4,40
2,20	3,50	4,90	2,70
2,30	4,00	5,60	3,30
2,20	7,80	7,80	5,60
1,30	2,20	3,90	2,60
1,10	1,90	3,40	2,30
2,70	4,00	5,30	2,60
1,20	2,00	3,40	2,20
2,30	3,80	5,20	2,90
1,10	1,80	3,00	1,90
2,50	4,50	6,40	3,90
1,70	3,20	4,80	3,10
1,10	1,80	3,00	1,90
1,40	2,50	4,20	2,80
1,60	2,90	4,50	2,90
2,20	3,50	4,90	2,70
2,20	4,00	7,80	5,60
2,40	3,80	5,10	2,70
1,70	3,20	4,80	3,10
2,00	3,50	5,00	3,00
3,60	6,20	7,40	3,80
,10	2,50	6,10	6,00
1,00	1,60	2,60	1,60

Control adults:

P10	P50	P90	bandwidth
1,40	2,20	3,70	2,30
2,20	3,50	4,90	2,70
1,70	3,20	4,80	3,10
1,40	2,50	4,20	2,80
1,60	2,90	4,50	2,90
1,80	3,40	5,10	3,30
1,70	3,20	4,80	3,10
2,20	3,50	4,90	2,70
1,80	3,20	4,70	2,90
1,60	2,90	4,50	2,90
1,70	3,20	4,80	3,10
1,20	2,00	3,40	2,20
2,20	3,70	5,20	3,00
2,30	4,00	5,60	3,30
1,40	2,50	4,20	2,80
2,30	3,80	5,20	2,90
1,10	2,20	4,10	3,00
1,30	2,20	3,90	2,60
1,60	2,90	4,50	2,90
2,50	4,00	5,40	2,90
1,10	2,00	3,50	2,40
1,70	3,30	5,30	3,60
1,40	2,20	3,70	2,30
2,80	4,20	5,60	2,80
1,40	2,20	3,70	2,30
2,00	3,50	5,00	3,00
1,20	2,10	3,90	2,70
2,00	3,50	5,00	3,00
3,10	4,50	5,90	2,80
1,20	2,00	3,40	2,20
1,40	2,20	3,70	2,30
1,40	2,50	4,20	2,80
1,10	2,00	3,50	2,40
1,70	3,20	4,80	3,10
1,60	2,90	4,50	2,90
1,80	3,60	5,60	3,80
1,10	1,80	3,00	1,90
1,30	2,20	3,90	2,60
2,20	3,50	4,90	2,70
2,50	4,00	5,40	2,90
1,60	2,90	4,50	2,90
1,40	2,50	4,20	2,80
3,30	4,70	6,00	2,70
1,80	3,40	5,10	3,30
1,30	2,40	4,50	3,20
1,60	2,90	4,50	2,90
1,40	2,50	4,20	2,80
1,30	2,20	3,90	2,60
1,40	2,60	4,70	3,30
1,60	2,90	4,50	2,90
2,70	4,00	5,30	2,60
1,80	3,20	4,70	2,90
,30	3,00	6,30	6,00
3,30	4,50	5,60	2,30
1,30	2,60	4,30	3,00
1,70	3,20	4,80	3,10
2,00	3,70	5,40	3,40
1,80	3,20	4,70	2,90
1,40	2,20	3,70	2,30
2,20	3,50	4,90	2,70
1,10	1,80	3,00	1,90
1,60	2,90	4,50	2,90
2,50	4,00	5,40	2,90
2,40	3,80	5,10	2,70
1,40	2,20	3,70	2,30
1,40	2,50	4,20	2,80
1,40	2,50	4,20	2,80
2,40	3,80	5,10	2,70
2,40	3,80	5,10	2,70
1,50	3,00	4,70	3,20
1,40	2,50	4,20	2,80
1,10	2,00	3,50	2,40
1,60	2,90	4,50	2,90
1,80	3,20	4,70	2,90
1,40	2,20	3,70	2,30
1,30	2,20	3,90	2,60

133 Number of cases listed: 133

APPENDIX 2

TABLE 21 Z-score data of the individual infants' proportional data in the imitation task.

GR+ infants	zata/a1%	zata/t%	zata/a2%	zatta/a1%	zatta/t%	zatta/a2%
1	.4838	.8914	-1.510	-.8216	.3918	.1029
2	.	.	.	1.3577	-1.539	1.0964
3	.	.	.	.	.	.
4	-.9299	1.8760	-1.428	-1.078	1.3216	-1.001
5	.	.	.	.	.	.
6	3.2101	-1.008	-1.428	.	.	.
7	.0798	-.9372	1.0313	.	.	.
8	.7867	-.3745	-.1163	.5885	-.6096	.4340
9	.7867	.3287	-1.018	-.3088	-.5381	.9860
10	-.9299	.9617	-.3622	.	.	.
11	-1.435	2.2980	-1.428	-1.206	1.4647	-1.222
12	.	.	.	.8449	-1.682	1.8691
13	.2818	-.3042	.1296	.9731	-1.253	.9860
14	-1.334	-.3745	1.5232	-.9498	.1772	.5444
15	.1808	.8914	-1.182	.	.	.
16	-.1221	-1.218	1.4412	.	.	.
17	.	.	.	.	.	.
18	.	.	.	-.8216	.5348	-.1179
19	.2818	-.5855	.4575	.8449	-.6811	.4340
20	-1.233	.9617	-.1983	.	.	.
21	.	.	.	.	.	.
22	.2818	-.3745	.2116	1.6141	-2.040	1.7587
23	-1.233	2.3683	-1.756	.2039	.1772	-.3387
24	-1.738	2.5089	-1.428	.5885	-1.253	1.4275
25	-1.233	.6101	.2936	.	.	.
26	.7867	-1.289	.7854	.2039	-.0374	-.1179
27	.	.	.	.	.	.
28	-.6270	.1881	.2936	1.3577	-.7527	-.0075
29	-.3241	-.3042	.6215	1.1013	-1.897	2.0898

GR- infants	zata/a1%	zata/t%	zata/a2%	zatta/a1%	zatta/t%	zatta/a2%
1	.1808	-1.359	1.4412	.	.	.
2	.	.	.	.	.	.
3	.0798	.6101	-.7721	.2039	.6779	-1.222
4	.6857	-.0932	-.4442	.2039	-1.468	2.0898
5	-1.435	-1.148	2.4249	.0758	-.2520	.2132
6	-1.233	-.0229	1.0313	-.9498	1.1786	-.8906
7	.	.	.	-1.206	1.6077	-1.443
8	.3828	.8914	-1.264	-.3088	-.0374	.3236

TABLE 21 (continues)

GR-infants	zata/a1%	zata/t%	zata/a2%	zatta/a1%	zatta/t%	zatta/a2%
9	.	.	.	.	.	.
10	.4838	.1881	-.6901	.7167	-.5381	.3236
11	1.4935	-.4449	-.6901	.	.	.
12	.	.	.	-.6934	.1772	.3236
13	.	.	.	-.4370	.5348	-.4491
14	.5847	.1881	-.6901	-1.334	1.3931	-1.111
15	.5847	-.0229	-.4442	1.1013	-.7527	.3236
16	1.6955	-1.218	.0477	.	.	.
17	.	.	.	.	.	.
18	.	.	.	.	.	.
19	.	.	.	1.7423	-.2520	-1.111
20	.	.	.	.	.	.
21	-.0211	-..932	.1296	-.6934	.8925	-.7802
22	.	.	.	.5885	-.6096	.4340
23	-.6270	-.5855	1.1953	.	.	.
24	.	.	.	.0758	.2487	.-5595
25	-.5260	-.3042	.7854	.0758	-.1804	.2132
26	.3828	.2584	-.6081	.3321	.0341	-.3387
27	-.2231	-.5855	.8674	-1.206	1.6792	-1.553
28	-.5260	-.3042	.7854	-.9498	1.1070	-.8906
29	-.1221	.3991	-.2802	-.4370	.6063	-.4491
30	.	.	.	-1.206	1.0355	-.6699
31	.	.	.	.	.	.
32	.8877	-1.570	1.1133	-.6934	1.2501	-1.332
33	.	.	.	3.0242	-1.325	-.5595
34	-.8290	-.1636	.8674	.0758	.3918	-.6699
35	1.5945	-1.148	.0477	-1.591	-.3235	1.8691

GR+ infants	zmato: m%	zmato: a%	zmato: t%	zmato: o%	zmatto: m%	zmatto: a%	zmatto: t%	zmatto: o%
1	.	.	.	.	.	.	.	.
2	.0527	.9002	.1226	-.6384	-.5024	1.6125	-.4636	-.6085
3	-1.704	1.1635	-1.616	1.6603	.8186	.3091	.1014	-.8828
4	.8333	.9002	-1.389	.5506	.8186	.1462	-.5766	.2145
5	-1.313	2.3484	-.1797	-.6384	.	.	.	.
6	.	.	.	.	.	.	.	.
7	.	.	.	.	.	.	.	.
8	-1.508	1.6901	-.1042	-.3213	-.5024	-.0167	-.0116	.3517

TABLE 21 (continues)

GR+ infants	**zmato : m%**	**zmato :a%**	**zmato :t%**	**zmato :o%**	**zmatt o: m%**	**zmatt o:a%**	**zmatt o:t%**	**zmatt o:o%**
9	.0527	-.153	.2737	-.2421	.1581	-.1796	.2144	-.1970
10	.	.	.	.	.	.	.	.
11	.	.	.	.	.	.	.	.
12	-.9230	.5053	.0470	.0750	-.5024	-.5055	.1014	.6261
13	.	.	.	.	.	.	.	.
14	.	.	.	.	-1.603	.1462	.3274	.4889
15	.	.	.	.	1.0388	.1642	-1.481	1.0376
16	.	.	.	.	.	.	.	.
17	-.5327	.3736	-.1797	.2335	.	.	.	.
18	.6382	.7686	.3493	-1.114	-.5024	-.6684	1.4575	-1.020
19	1.2236	.5053	-.4821	-.2421	.3782	-.3426	-.3506	.6261
20	.8333	-.2847	-.9355	.7884	-.9428	.9942	1.3445	-.0598
21	-1.118	-1.470	2.0120	-7969	.8186	-.1796	-2.046	2.1349
22	-1.118	-.6796	1.1051	-.3212	-.5024	1.7754	-1.481	.6261
23	-1.313	-1.733	3.1456	-1.748	.8186	-.3426	.4404	-.7456
24	-.1424	-.5480	-.7088	1.1847	-1.383	-.9942	-1.029	2.5980
25	.	.	.	.	-.5024	-1.646	.2144	1.3119
26	.6328	1.4268	-.1042	-.9555	1.9194	.3091	-.8026	-.4713
27	-.1424	-.8113	-.3309	.7884	1.9194	.3091	-.8026	-.4713
28	.0527	.7686	1.2562	-1.827	.	.	.	.
29	1.4188	-4163	.5760	-.9555	.1581	-.0167	-.4636	.3517

GR- infants	**zmato : m%**	**zmato :a%**	**zmato :t%**	**zmato :o%**	**zmatt o: m%**	**zmatt o:a%**	**zmatt o:t%**	**zmatt o:o%**
1	.	.	.	.	.	.	.	.
2	.	.	.		-.0621	2.2642	-.3506	-1.431
3	.2479	-.1530	.5760	-.5591	.8186	-.1796	.4404	-.8828
4	.	.	.	.	.	.	.	.
5	.6382	-.2847	-.9355	.9469	.	.	.	.
6	.2479	-1.338	.0470	.7091	-1.163	-1.320	.8925	.6261
7	.	.	.	.	.	.	.	.
8	-.5327	.3736	.9539	-.9555	-.7226	.4721	.8925	-1.020
9	-1.704	-.9429	-.1797	1.5017	2.5800	-.6684	.9156	-.0598
10	.	.	.	.	.	.	.	.
11	-.7279	1.6901	-1.238	.5506	-1.823	2.2642	.7795	-1.706
12	.	.	.	.	.	.	.	.
13	.	.	.	.	.	.	.	.

TABLE 21 (continues)

GR-infants	zmato : m%	zmato :a%	zmato :t%	zmato :o%	zmatt o: m%	zmatt o:a%	zmatt o: t%	zmatt o:o%
14	.	.	.	.	.	.	.	.
15	-.5327	-.2847	1.7852	-1.510	-1.383	.9608	.4404	-.4713
16	.	.	.	.	-1.383	1.9384	-.9156	.3517
17	1.6139	1.0319	-.2553	-1.035	.	.	.	.
18	.	.	.	.	1.0388	-1.483	1.1185	-.7456
19	.	.	.	.	.	.	.	.
20	-.1424	.2420	-1.011	.9469	.	.	.	.
21	.	.	.	.	.	.	.	.
22	.	.	.	.	-.2823	1.1238	.2144	-1.020
23	.6382	.6369	-.7088	.0750	.3782	-.3426	.7795	-.8828
24	-.9230	-.9429	-.4065	1.3432	.3748	-.9942	.8925	-.6085
25	-.1424	-.9429	-.8599	1.5017	-.9428	-.3426	1.4575	-.7456
26	.	.	.	.	.	.	.	.
27	.	.	.	.	-.02823	-1.320	.8925	.0774
28	2.1994	-.0213	-.2553	-.5591	-.5024	-.6684	1.2315	-.4713
29	-.1424	-1.075	-.5576	1.2639	.8186	-.0167	.2144	-.8828
30		.	.	.	.	.	.	.
31	1.4188	-.8113	1.3318	-1.510	.	.	.	.
32	.	.	.	.	-.5024	-.9942	1.4575	-.6085
33	.0527	-1.338	.0470	.7091	.8186	-.3426	.-4636	.4889
34	.2479	-1.075	-.3309	.8676	.	.	.	.
35		.	.	.	1.4791	.9608	-2.498	1.3119

APPENDIX 3

TABLE 22 Descriptive data on the model productions in Experiment 6 of the pseudowords *ata* and *atta* as well as those of the words *mato* and *matto*.

ATA-model	**a1:ms**	**t:ms**	**a2:ms**	**a1:%**	**t:%**	**a2:%**	**total:ms**		
	126	114	175	30	27	42	415		
ATTA-model	**a1:ms**	**t:ms**	**a2:ms**	**a1:%**	**t:%**	**a2:%**	**total:ms**		
	98	290	122	19	57	24	510		
MATO-model	**m:ms**	**a:ms**	**t:ms**	**o:ms**	**m:%**	**a:%**	**t:%**	**o:%**	**total:ms**
	90	102	102	194	18	21	21	40	488
MATTO-model	**m:ms**	**a:ms**	**t:ms**	**o:ms**	**m:%**	**a:%**	**t:%**	**o:%**	**total:ms**
	87	116	277	165	13	18	43	26	645

TABLE 23 The mean duration and standard deviations in the *ata* word produced by girl infants and boy infants.

		Girls			Boys		
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
ata: /a1/:ms	21	110	55	21	117	55	NS
ata: /t/:ms		166	124		185	139	NS
ata: /a2/:ms		179	77		182	85	NS
ata: /a1/:ms		25	12		25	8	NS
ata: /t/:ms		35	14		36	15	NS
ata: /a2/:ms		40	14		39	11	NS
/a1/:/a2/		2.0	1.5		1.7	.7	NS
/a2/:/t/		1.4	.9		1.4	1.0	NS
total:ms		455	146		473	215	NS
distance: ms		2626	1741		2328	1703	NS

TABLE 24 The mean duration and standard deviations in the *atta* word produced by girl infants and boy infants.

	Girls			Boys			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
atta: /a1/:ms	23	127	37	20	119	48	NS
atta: /t/:ms		284	101		292	180	NS
atta: /a2/:ms		158	52		154	63	NS
atta: /a1/:ms		23	6		22	10	NS
atta: /t/:ms		49	11		49	17	NS
atta: /a2/:ms		28	8		28	11	NS
/a1/:/a2/		1.2	.4		1.5	.8	NS
/a2/:/t/		1.9	..9		2.2	1.5	NS
total:ms		569	125		566	193	NS
distance:ms		2225	995		2879	2118	NS

TABLE 25 The mean duration and standard deviations in the *mato* word produced by girl infants and boy infants.

	Girls			Boys			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
mato: /m/:ms	20	43	23	16	52	25	NS
mato: /a/:ms		101	46		116	42	NS
mato: /t:/ms		161	104		186	91	NS
mato: /o/: ms		179	110		222	80	NS
mato: /m/:%		10	6		9	4	NS
mato: /a/:%		22	8		21	7	NS
mato: /t/:%		33	14		32	13	NS
mato: /o/:%		36	14		39	12	NS
o/a		1.9	1.1		2.1	1.2	NS
o/t		1.4	1.2		1.5	.9	NS
total:ms		485	150		589	98	*
distance:ms		2373	1953		2225	1530	NS

TABLE 26 The mean duration and standard deviations in the *matto* word produced by girl infants and boy infants.

	Girls			Boys			
Parameters	*n*	*Mean*	*SD*	*n*	*Mean*	*SD*	*Sig.*
matto: /m/:ms	15	57	29	23	58	32	NS
matto: /a/:ms		115	23		100	42	NS
matto: /t:/ms		335	135		310	139	NS
matto: /o/: ms		173	104		150	84	NS
matto: /m/:%		8	4		10	5	NS
matto: /a/:%		17	6		17	6	NS
matto: /t/:%		49	7		49	10	NS
matto: /o/:%		25	8		24	7	NS
o/a		1.6	.9		1.7	.9	NS
t/o		.5	.3		.5	.3	NS
total:ms		682	209		619	231	NS
distance:ms		2433	1316		1935	747	NS

YHTEENVETO

Tutkimuksessa selvitetään miten äänteiden kesto vaikuttaa niiden luokitteluun suomenkielisillä dyslektikkoaikuisilla sekä heidän lapsillaan. Suomen kielen yksi erityispiirre on äänteiden kvantiteetti. Ratkaisevassa asemassa suomen kvantiteetissa on juuri kesto, jonka käyttäminen keskeisenä tutkimusparametrinä on oleellista, sillä suomen kielen fonologiassa pituutta käytetään sanojen erottamiseen toisistaan. Äänteiden luokittelu niiden keston mukaan ei ole kuitenkaan suoraviivaista. Pituuden luokittelemiseen ei vaikuta ainoastaan äänteen absoluuttinen kesto vaan myös sanansisäiset suhteelliset kestot. Esimerkiksi lyhyeksi luokittelemamme äänne voi toisessa sana-asemassa olla yli kaksi kertaa niin pitkä kuin toisessa, ja siltikin nämä kaksi kestoltaan erilaista äännettä luokitellaan samaan lyheen kvantiteettiluokkaan. Toisin sanoen meillä on ainoastaan kaksi kvantiteettiluokkaa: äänteet havaitaan joko lyhyiksi tai pitkiksi, vaikka objektiivisesti mitattuna kestoja on loputon määrä. Tämän lisäksi on huomattava, että kvantiteettiluokittelu on tiettyyn pisteeseen saakka subjektiivista, sillä oman kielikokemuksensa perusteella jokainen sijoittaa äänteiden fyysiset kestot oman asteikkonsa mukaisesti joko lyhyisiin tai pitkiin äänteisiin.

Kvantiteetti ei ole ainoastaan puheen piirre vaan suomessa se tulee esille myös kirjoituksessa. Äänteet, jotka havaitaan ja luokitellaan pitkinä, kirjoitetaan kahdella kirjaimella ja vastaavasti äänteet, jotka havaitaan lyhyinä, kirjoitetaan yhdellä kirjaimella. Kirjoitukseen ja lukemiseen tutkimus liittyy siinä mielessä, että työssä selvitetään erityisesti dysleksian (lukihäiriön) yhteydessä keston prosessointia puheen havaitsemisessa ja tuottamisessa. Aikaisemassa tutkimuksessa on todettu, että suomenkieliset dyslektikot tekevät kirjoitetussa tekstissä suhteellisesti selvästi enemmän kvantiteettivirheitä muihin virheisiin verrattuna. Tämän lisäksi puheen havaitsemisen puolelta on tuloksia siitä, että dysleksiaan saattaa liittyä temporaalisen prosessoinnin ongelmia. Vaikka tätä on selvitetty useassakin kansainvälisessä tutkimuksessa, mitään yksiselitteistä tietoa ei ole olemassa ehdotetusta temporaalisen prosessoinnin ongelmasta dyslektikoilla, ja siksi tätä hypoteesia selvitetään kokeellisten testien avulla tässä tutkimuksessa.

Tämän työn suunnittelussa on käytetty hyväksi dysleksiatutkimuksien tuloksia, joiden mukaan dysleksiaa esiintyy perheittäin. Tutkimuksessa on koehenkilöinä dyslektikkoaikuisia ja heidän 6 ja 18 kuukauden ikäisiä lapsiaan sekä vastaavat ryhmät verrokkiperheistä, joissa ei ole dysleksiaa. Näin pystytään etsimään dysleksian varhaisia ennusmerkkejä lapsilta jo kauan ennen kuin he opettelevat lukemaan ja kirjoittamaan, jolloin dysleksia pystytään varsinaisesti diagnosoimaan.

Aikaisemmat havaitsemistutkimukset osoittavat, että jo 6 kuukauden ikäisillä lapsilla on kyky luokitella selkeästi erilaisia puheääniä omiin luokkiin. Kuitenkin on olemassa vielä hyvin vähän tietoa siitä, pystyvätkö pienet lapset luokittelemaan puheääniä niiden prosodisten ominaisuuksien perusteella ja erityisesti äänten kestojen suhteen. Tässä tutkimuksessa 6 ja 18 kuukauden ikäiset lapset ovat keskeisessä osassa kahdessa osatutkimuksessa. Koska dysleksiatutkimukset ovat kohdistuneet nuorimmillaan 2,5 vuotiaisiin lapsiin, tämä on ensimmäinen näin pieniä lapsia käsittelevä tutkimus. Samalla tutkimuksessa saadaan tietoa normaalista kielenkehityksestä suomenkielisessä ympäristössä.

Tutkimus koostuu kaikkiaan kuudesta kokeellisesta osatutkimuksesta. Ensimmäisessä ja toisessa havaitsemisen osatutkimuksessa selvitetään miten keston muunteleminen klusiilin sulkeumavaiheessa epäsanoissa *ata* ja *atta* vaikuttaa niiden tunnistamiseen. Koehenkilöinä ensimmäisessä osatutkimuksessa oli 32 opiskelijaa. Heistä 21 oli mukana myös toisessa osatutkimuksessa. Tutkimukset erosivat toisistaan siinä, millä tavalla ärsykejatkumot oli rakennettu: ensimmäisessä ärsykejatkumo oli muodostettu alkuperäisestä *ata*-sanasta pidentämällä klusiilia 20 ms kerrallaan ja toisessa jatkumo oli rakennettu *atta*-sanasta lyhentämällä klusiilia 20 ms kerrallaan. Molempien osatutkimusten tulokset osoittavat, että epäsanat luokitellaan selkeästi joko VKV-rakenteisiksi *ata*-sanoksi tai VKKV-rakenteisiksi *atta*-sanoiksi riippuen konsonantin kestosta. Kategorioiden raja on suhteellisen jyrkkä ja foneemien raja-alue kapea, eli ärsykkeet havaitaan ja tunnistetaan selkeästi. Tulokset osoittavat myös, että tutkittavissa sanarakenteissa vokaalienvälisen konsonantin kesto vaikuttaa ainoastaan kyseisen äänteen kategorisointiin. Toisaalta sanan sisällä äänteiden suhteelliset kestot vaikuttavat siihen, miten kyseinen äänne kategorisoidaan. Siten kvantiteetti on - toisin kuin kirjoitetusta kielestä voisi päätellä - sanan kokonaisrakenteen ominaisuus. Näitä opiskelijoille tehtyjä identifikaatiotestien tuloksia käytetään hyväksi kategoristointitehtävien 3 ja 4 suunnittelussa.

Osatutkimuksissa 3 ja 4 selvitetään dyslektikkojen ja heidän lapsiensa kategorisointikykyä käyttämällä ärsykkeinä samaa jatkumoa kuin osatutkimuksessa 1. Tutkimusmetodina 6 kuukauden ikäisillä lapsilla käytettiin behavioraalista päänkääntötestausta (head-turn paradigm). Siinä hyödynnetään pienen lapsen luonnollista taipumusta kääntää katseensa siihen suuntaan, mistä uusi, erilainen ääni tulee. Lapselle näytettiin rummuttavaa mekaanista lelua palkkiona oikea-aikaisesta päänkäännöstä. Aikuisten testi oli sama kuin lapsilla sillä erotuksella, että aikuiset painoivat nappia kuullessaan sanan *atta*. Tutkimustuloksissa on mukana 133 aikuisen ja 89 lapsen kategorisointiaineisto. Tulokset osoittavat, että jo 6 kk:n ikäiset lapset kykenevät aikuisten tavoin luokittelemaan puheärsykkeet kahteen selkeään luokkaan ärsykkeiden kvantiteetin mukaan. Lisäksi tuloksena on, että sekä 6 kk:n ikäiset dyslektikkovanhempien lapset että aikuiset dyslektikot vaativat merkitsevästi pidemmän keston havaitakseen pitkän kvantiteetin verrattuna verrokkeihin. Ryhmien väliset erot ovat tilastollisesti merkitseviä, mikä tekee tuloksista merkittäviä. On kuitenkin huomattava, että aikuisten tuloksissa on selvästi erotettavissa ne yksilöt, joiden responsit epäsanoihin osoittivat epävarmuutta. Tämä tuli esille paitsi epäsanojen kategorisoimisessa myös reaktioajoissa. Tulokset antavat viitteitä siitä, että dyslektikoilla saattaa olla vaikeuksia puheen auditiivisen tiedon temporaalisessa prosessoinnissa ja että nämä vaikeudet ovat esillä jo hyvin varhaisessa lapsuudessa.

Osatutkimuksissa 5 ja 6 tutkitaan osioissa 3 ja 4 mukana olleiden aikuisten ja lasten puhetta. 18 kk:n ikäisten lasten tehtävänä on imitoida videolla esitettyjä epäsanoja *ata* ja *atta* sekä sanoja *mato* ja *matto*. Imitoiduista tuotoksista tutkitaan äänteiden absoluuttisia ja suhteellisia kestoja. Tulokset osoittavat, että suhteellisten kestojen osalta lapset pystyivät tuottamaan sanat lähes aikuisten tavoin. Eniten lasten tuotokset poikkesivat aikuisista sananloppuisten kestojen suhteen. Varsinkin (K)VKKV-rakenteissa loppuvokaalit olivat lapsilla pitempikestoisia kuin aikuisilla. Vertailtaessa lapsiryhmien tuotoksia tulokset osoittavat, että dysleksiariskilasten tuotokset olivat kestoiltaan verrokkilasten tuotoksia kauempana aikuisten mallista. Lisäksi tuotokset aikuisten nimeämistehtävästä viittavat siihen, että dyslektikkoaikuisilla KVKV-sanojen loppuvokaalin kesto poikkeaa verrokkiaikuisten vastaavasta. Tämä tulos saattaa johtua murteellisista eroista ryhmien välillä, koska aikaisemmat tutkimukset ovat osoittaneet, että juuri kyseisen rakenteen sananloppuisessa vokaalissa ilmenee suomen eri murteissa suuriakin kestoeroja. On kuitenkin mielenkiintoista havaita, että sekä dyslektikkoaikuisten että dysleksiariskilasten ryhmässä kestosuhteet tuotettiin samankaltaisesti ja että nämä tuotokset poikkesivat verrokkiaikuisten ja -lasten keskenään samankaltaisista tuotoksista. Tutkimuksessa esitetäänkin ajatus, että havaitut erot dyslektikkoryhmien kestojen havaitsemisessa ja tuottamisessa saattavat osaltaan johtua geeniperimän aikaansaamasta temporaalisen prosessoinnin poikkeavuudesta. Toisaalta täytyy ottaa huomioon myös se seikka että varsinkin pienet lapset saavat puheen ja kielen mallin juuri vanhemmiltaan, ja tällainen sosiaalinen kanssakäyminen saattaa osaltaan vaikuttaa siihen, miten lapset kategorisoivat puheääniä myös keston suhteen. Kategoriat ovat muokkautuvia, mutta perustan niille antavat juuri ensimmäiset elinvuodet.

Tutkimustulokset puheen tuottamisesta ja puheen havaitsemisesta ovat hyvin samansuuntaisia. Kokonaisuudessaan ne viittaavat vahvasti siihen, että dysleksiaan saattaa osaltaan liittyä temporaalisen prosessoinnin häiriö, joka tulee esille sekä puheen tuottamisessa että puheen havaitsemisessa. Tällä saattaa olla merkitystä tulevaisuudessa siinä, että varhaisia ennusmerkkejä mahdollisesta dysleksiasta voidaan etsiä juuri temporaalisen prosessoinnin tehtävillä. Vaikka tämän tutkimuksen löydökset ovat hyvinkin selkeästi suuntaa-antavia, asia vaatii vielä lisäselvityksiä. Vaikuttaa kuitenkin lupaavasti siltä, että merkittävästi elämään vaikuttavan dysleksian juurille ollaan mahdollisesti pääsemässä ja että tulevaisuudessa dysleksiaa voidaan ehkä joissakin tapauksissa lieventää aikaisen intervention avulla.