Detection of rise time and its connections to speech perception and reading ability

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Abstract

Studies of perception of amplitude modulation (AM) and brain responses to AM, as well as perceptual centre (P-centre) experiments, have shown high correlation to language. Both have in common changes in the amplitude envelope of sounds. We studied the relationship between detection of sinusoidal rise time stimuli, speech perception and reading skills. Detection of different rise times within sound trains or pairs was used as an independent variable. Significant, positive correlation to the correctness of non-word writing and other language tests measuring speed and accuracy of reading, but not comprehension, were found. As detection of deviants of shorter duration or lower intensity were found not to correlate to language skills in these experiments we conclude that detection of dynamic temporal changes in sound stimuli, if not rise times per se, may be an important auditory skill associated with speech perception.

1. Introduction

Rise times are amplitude changes in the beginning of sounds. Rise time tells us how long it takes for a sound to reach its maximum amplitude level. There are number of studies that have used complex stimuli with several rise times which have shown connections to speech perception and reading ability and also dyslexia (Goswami et al., in print; Menell & McAnally, 1999; Lorenzi et al., 2000). Rise times could be linked to individual phoneme detection via voice-onset-time (VOT) of which rise time is a major part. For example the VOTs of /b/ and /p/ distinguish these phonemes from each other. Rise times of 10 to 50 ms are typical for vowels (Broecke & Heuven, 1983). Rise times can also affect the detection of speech rhythm at a word level with longer amplitude modulations (Goswami et al., in print).

Dyslexia is a difficulty in learning to read despite otherwise normal cognitive skills. Problems in phonological awareness in the auditory rather than visual modality (but sometimes also in visual modality, (Stein et al., 2000)) are manifested in people with dyslexia (Habib, 2000). People with dyslexia have been reported to suffer from perceptual difficulties detecting auditory pitch changes (Baldeweg, 1999), perceptual centres (P-centres) (Scott, 1998), rapidly presented stimuli (Tallal, 1980), amplitude (Menell, 1999) and frequency modulations (Witton et al., manuscript, Laine, 2002), and sound durations (Richardson et al., manuscript). Other perceptual atypicalities among individuals with dyslexia have been found in auditory illusions and segregation (Helenius et al., 1999). On the other hand, Serniclaes et al. (2001) found that dyslexics' discrimination of sinewave sounds (reduced from actual syllables) within phonetic categories was better than controls. This could indicate that people with dyslexia do not utilise as strong categorical representations of speech sounds as normal readers do.

Baldeweg et al. (1999) found that there were differences between adults with dyslexia and controls in their discrimination performance on a pitch detection task, and that this ability was correlated with a non-word reading task in people with dyslexia. However, Alcock et al. (2000) tested a family with inherited developmental speech and language disorder and found that the family did not differ in detection of pitch in a musical context. They did, however, differ in rhythm detection and production from controls. This would suggest impaired timing abilities. Goswami et al. (in print) found detection of Perceptual centres, or 'P-centres' to be less categorical in children with dyslexia compared to age matched controls. The P-centre categorisation slope was correlated to several language tests. This finding supports the impaired rhythm detection finding of Alcock et al. (2000) as P-centres are proposed to be connected to rime-onset detection i.e. to rhythm of speech (Goswami et al., in print). Scott (1998) defines P-centres as not necessarily the exact middle point of the physical length of a word but rather were the middle point is perceived to be. This is measured by presenting repeatedly words such as street and seat and asking people to adjust them so that they are presented in rhythm. The resulting p-centre point is mainly defined by rise times. In an auditory segregation task Helenius et al. (1999) showed that adults with dyslexia perceived alternating tone pips as two separate sound streams at an inter-stimulus interval (ISI) of 210 ms when for the control group the ISI was 130 ms. This means that people with dyslexia fused the separate sounds together with longer ISIs than controls.

Serniclaes et al. (2001) experimented with sinewave acoustic and speech sounds. They discovered that when the sinewave was perceived as a non-speech whistle instead of a speech-like sound, the discrimination of the sounds was better among participants with dyslexia. In speech sounds subjects with dyslexia were less categorical perceivers than controls. This suggests that as the same sounds were told to be either non-speech whistles or speech, the reference to where the sounds are compared to changed. The only changing aspect of these sounds was pitch, that changed in a continuum according to the /ba/ - /da/ formants. In their data participants with dyslexia, did not have any difficulty in detecting pitch changes within sounds. This is quite the opposite finding from Baldeweg et al. (1999) unless the detection of pitch change within sound is not impaired but detection of pure frequency differences between sounds are impaired in participants with dyslexia although frequency modulation studies (Witten et al., manuscript) would suggest otherwise. Also, in the Serniclaes et al. (2001) article adding amplitude modulation to sinewave sounds made them clearly speech-like supporting the assumption that amplitude modulation may be important for speech intelligibility.

In an experiment by Tallal (1980) it was shown that reading disabled children's rapid temporal processing was impaired. These children performed equally well as controls on auditory discrimination tasks when the ISI was over 428 ms, but when the ISI was shortened reading disabled children faired worse than controls. A significant correlation was found between the rapid temporal discrimination task and the nonsense word reading task.

Rousseau et al. (2001) reported that the time interval detection (the threshold where one can detect that two time intervals are different) grew more steeply with increasing time intervals in one subject with dyslexia compared to six controls. This difference started to emerge at 300 ms intervals.

A study with amplitude modulation (Lorenzi et al. 2000) found an elevated amplitude modulation threshold at 4 and 1024 Hz modulation rates in six children with dyslexia. It was concluded that some people with dyslexia may be deficient in processing auditory temporal-envelopes.

The threshold of amplitude modulation detection was found to be higher for subjects with dyslexia than among controls by Menell & McAnally (1999) as well. Also, the detection of amplitude modulation depth was correlated to non-word and word reading speed and errors made in the non-word test. Accordingly the amplitude modulation following response of the evoked brain potentials was found to be smaller in amplitude in the dyslexia group (Menell 1999, McAnally 1997). Laine (2002) found also that 20 Hz AM together with phonological processing explained over 30 % of the variation of word reading. In the same study 2 Hz and 40 Hz FM was connected to reading skills but also to non-linguistic skills indicated by Raven's The Coloured Progressive Matrices test (Raven et al, 1992). Poor and normal readers groups differed from each other in 40 Hz FM thresholds.

FM and AM studies are often motivated by referring to the possibility that the magno cells of the sensory systems may be impaired in dyslexia. The magno cells are larger neurones that are specialised in rapid temporal processing. These magno cells have been found to be atypically small of the medial geniculate nucleus in the thalamus in dyslexics (Stein, manuscript).

Tallal (1980) suggests that language impaired children have problems in detecting rapidly presented auditory stimuli and it has motivated her to believe that language impairments have an auditory basis and that these are not speech specific. We follow this line of thinking which a number of mentioned studies support and use in the following studies pure tones instead of speech stimuli. Both amplitude modulation and P-centres are based on variation of sound intensity within single stimuli creating several rise times within the sound. But the previous experiments (Menell & McAnally, 1999; Goswami et al., in print) have not looked explicitly into the role of this basic unit i.e. rise time. The experiments described here tried to look into the effect of rise time detection of participants with poor and normal reading skills. As rise time is a change in the amplitude of the sound over time, the effects of intensity and sound duration were also examined.

The aim was to see if rise times have a connection to language skills involving reading and speech perception.

The basis for such assumptions is derived from earlier studies that suggest a temporal processing deficit underlying dyslexia (Menell & McAnally 1999). The nature of the deficit, however, is still obscure. Two temporal perceptual features have received attention in this connection – duration of speech units and rise times of the sound elements. Rise times are difficult to detect in general (a rise time of about 20 % of the total sound length is close to the just noticeable difference) (Broecke & Heuven, 1983) and amplitude modulations (Menell & McAnally, 1999; Goswami et al., in print) have shown close relationships with speech perception that could explain some of the variance in speech perception.

Next four experiments will be described. In the first one adult dyslexics and controls listened to tone pairs with different rise times. The aim was to see if people with dyslexia and control participants would differ in their detection of rise times. The second experiment was done with children who listened to stimulus trains of five tones. In this study we wanted to see that it was not sound onset time that was being detected in the previous study. This still left intensity detection as a possibility of being confounded in rise time detection and this is why still another experiment was done. In the third experiment participants were young adults and they listened to stimulus trains containing both rise time and intensity targets. The fourth experiment was done to in order to see how different rise times are connected to language skills. Questions and hypothesis for each experiment are at the beginning of each study. The major issue was to see if rise time detection was connected to reading skills.

2. Experiment I

The aim of the first experiment was to see if detection of rise times of single stimuli was connected to reading skills as P-centres and AM studies would suggest. Different inter-stimulus intervals were used to see if the rate of stimulus presentation has an effect and whether the discrimination of rise times is intact but the rate of information processing is impaired.

2.1 Subjects

There were 48 adult subjects of which 27 had dyslexia and 21 were controls. 23 (4 controls, 19 dyslexics) had been tested previously with several reading tests mentioned in procedure. The subjects were parents of the children followed in the Jyväskylä Longitudinal Study for Dyslexia. The diagnostic criteria for dyslexia was that their reading speed or accuracy in oral text reading and in at least two single word measures was one standard deviation lower from the norm. In addition their IQ had to be over 85, assessed with the Raven B, C, and D matrices (Raven, Court & Raven, 1992).

2.2 Stimuli

All stimuli in Experiments I, II, III and IV were created with Sound Forge 4.0. The sampling rate was 22050 Hz and sample size 8 bits.

The inter-trial interval (ITI) (onset-to-onset) between the sound pairs was 1700 ms. In three blocks the interval between the two stimuli in a pair was (onset-to-onset) 500 ms and in three blocks it was 250 ms. The subject heard thus six blocks each of which consisted of 106 pairs. A deviant stimulus appeared in 24 (23 %) of the pairs. In these the rise time of the second sound was different from the other sound in the pair. The standard had 10 ms rise time and fall time when the deviant had either 30 ms or 80 ms rise time and 10 ms fall time, see Figure 1. All sinusoidal sounds were 500 Hz and 100 ms duration.

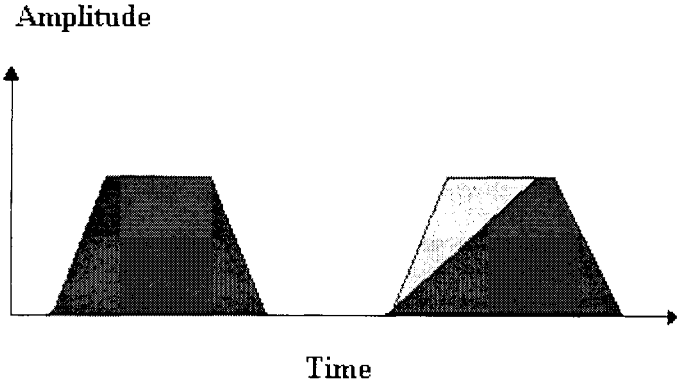

Figure 1. Illustration of the experimental stimuli. The lighter colour shows the difference in the sound rise time in deviant stimuli.

2.3 Procedure

Adult subjects tried to detect the longer rise time stimulus from stimulus pairs repeatedly presented to them with occasionally unequal rise time within the second sound in the pair. Subjects had to decide whether the pair of sounds they heard was the same or not and indicate the detection of a different sound by pressing a mouse button. Subjects had 1700 ms to push a button to indicate they had heard a deviant sound.

The difference was demonstrated to subjects with example sounds that were repeated for a necessary number of times. The sounds were presented in a Cognitive Workshop display-program. Some (23) of the subjects were tested earlier in chapter reading task from which reading speed and reading errors were calculated, non-word reading task and masked word reading task.

2.4 Results

Both of the rise time deviants were easier to detect with the longer ISI (t = -2.448 p = 0.018 for the 80 ms deviant, t = -2.844 p = 0.007 for the 30 ms deviant), see Table 1 for means and standard deviations of the percentage of the correct answers. Figure 2. shows the distribution of the rise time variable that showed correlation to reading skills.

The participants with dyslexia and the control group differed statistically in the detection of 80 ms rise times with 250 ms ISIs (t = 2.174 p = 0.035). Control group was better in detecting the rise time on average detecting 57 % of the deviants while the dyslexia group's result was 40 %.

Results from the earlier reading tests carried out with subjects were compared to the results of the rise time detection task. Significant correlation between errors made in a non-word test, masked word reading test and reading speed was found (see Table 2). The composite variable of the language tests seen in Table 2 and the rise time detection task gave a correlation of r = 0.552, p = 0.006. For a scatterplot of the 80 ms rise time deviant with 500 ms ISI and the reading tasks combined see Figure 3.

Table 1. Means and standard deviations and the effect of ISI. Mean is the percent of correct items.

	Mean	Standard deviation
30 ms rise time, 500 ms ISI	26.08	28.25
80 ms rise time, 500 ms ISI	69.44	27.53
30 ms rise time, 250 ms ISI	19.18	23.74
80 ms rise time, 250 ms ISI	63.89	30.34

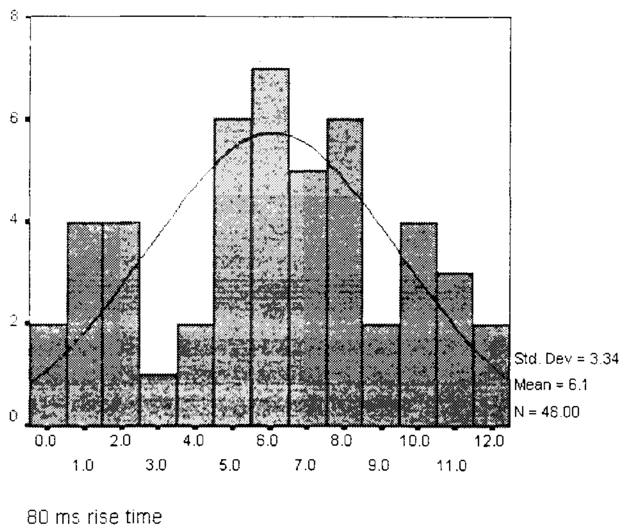

Figure 2. The distribution of the 80 ms rise time deviant. Correct detections out of 12.

Correlation between these composite variables, individual variables and rise time variables can be seen in Table 2. R^2 values for 80 ms rise time detection and composite variable of speed (passage reading in ms and reading speed in syllables per second) and accuracy (reading errors, accuracy non-words, accuracy masked word reading task) were 24,5 % and 36,2 %.

Table 2. Correlation between rise time detection and reading tasks. N = 23. N. s. = non-significant.

	30 ms rise time, ISI 500 ms	80 ms rise time, ISI 500 ms	30 ms rise time, ISI 250 ms	80 ms rise time, ISI 250 ms
Passage reading (ms)	n.s.	r = -0.488 p = 0.018	n.s.	r = -0.459 p = 0.027
Reading speed, syllables per sec	n.s.	r = 0.498 p = 0.016	n.s.	r = 0.466 p = 0.025
Reading errors	r = -0.447 p = 0.033	r = -0.551 p = 0.006	r = -0.439 p = 0.036	r = -0.495 p = 0.016
Accuracy non-words	n.s.	r = 0.496 p = 0.018	n.s.	r = 0.427 p = 0.042
Accuracy masked reading task	n.s.	r = 0.566 p = 0.005	n.s.	r = 0.508 p = 0.013
Speed	n.s.	r = 0.495 p = 0.016	n.s.	r = 0.465 p = 0.026
Accuracy	n.s.	r = 0.601 p = 0.002	n.s.	r = 0.533 p = 0.009

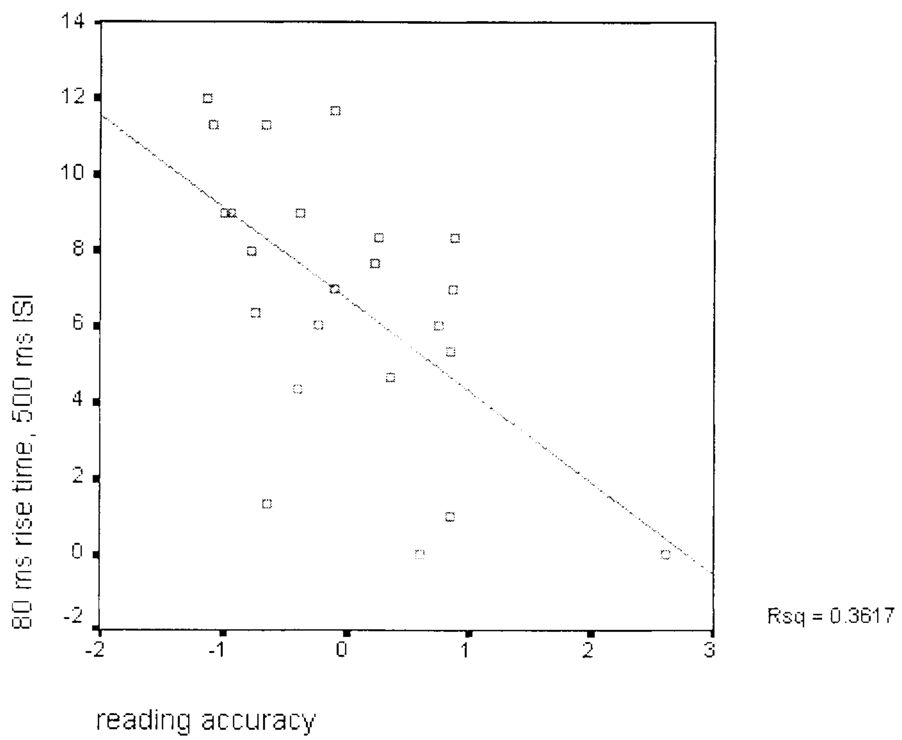

Figure 3. Scatterplot for combined reading variables and the 80 ms rise time with 500 ms ISI.

2.5 Discussion

Subjects found the rise time detection task extremely difficult. This was reflected by the floor effect in the detection of 30 ms rise times as they were difficult to detect for everyone. Varying the ISI had a statistically significant effect and the rise time task was easier with the longer ISI of 500 ms, which was expected. The rise time detection correlation to reading tests were actually higher for longer ISI than for shorter which was not expected because dyslexics are sometimes thought to have difficulties in detecting rapidly presented stimuli. Apparently not just the stimulus presentation rate can explain the results and the actual discrimination of rise time may be connected to writing skills and reading speed and accuracy.

3. Experiment II

The paired stimulus detection task was estimated to be too difficult. We then gave a couple of more standard sounds before the presentation of the deviant stimuli to make the detection task easier. Stimulus trains are thus used in the other three experiments. The purpose of this study was to see whether rise time detection is based on perceiving the stimuli as shorter when the rise time is longer meaning that the detection would be based on stimulus onsets. Also, we wanted to see if we could replicate the connection to reading skills.

3.1 Subjects

The participants were 56 (26 girls, 30 boys) eight-year-olds from three different 2nd grade classes. All pupils in these classes participated in the tests and no selection criteria were used beforehand.

3.2 Stimuli

The standard stimuli were 100 ms, 500 Hz, sinusoidal sounds with 10 ms rise and fall times. The sounds were presented in a five sound train with 150 ms ISIs and thus one train was 700 ms long. A deviant stimulus occurred on half of the stimulus trains as either the 3rd, 4th or 5th sound.
The deviant stimuli could be different on two features: rise time or length. The rise time deviant stimuli had a rise time of 50, 70 or 90 ms. The duration deviants were 15, 25 or 35 ms shorter than standards. In addition to being shorter, the duration deviants offset was synchronised to the other stimuli. This meant that the onset was 15, 25 or 35 ms later compared to the onset-to-onset intervals of the other stimuli in the train. See Figure 4 for illustration of the stimuli.
The ITI (inter-trial interval) was approximately two seconds as the tester pressed a mouse button when all of the children had marked their response on the response sheet.

70 ms rise time	83.3	20.9
90 ms rise time	83.1	18.8
85 ms duration	39.0	25.8
75 ms duration	62.5	22.8
65 ms duration	80.6	20.1
Pseudo-word, sum of correct responses	11.8	4.2
Reading comprehension, sum of correct responses	23.0	6.0

Figure 5. Distribution of the 50 ms rise time deviant. Correct detection out of 100 percent.

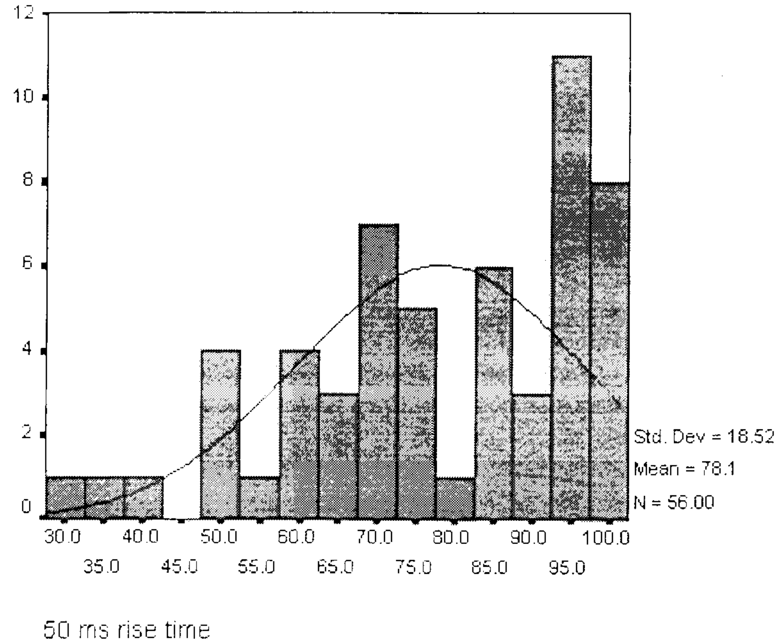

Table 4. Correlation between the pseudo-word spelling and the d' values of rise time detection, N=56.

Task	50 ms rise time	70 ms rise time	90 ms rise time
Pseudoword test	r = 0.367 p = 0.005	r = 0.313 p = 0.013	r = 0.302 p = 0.024

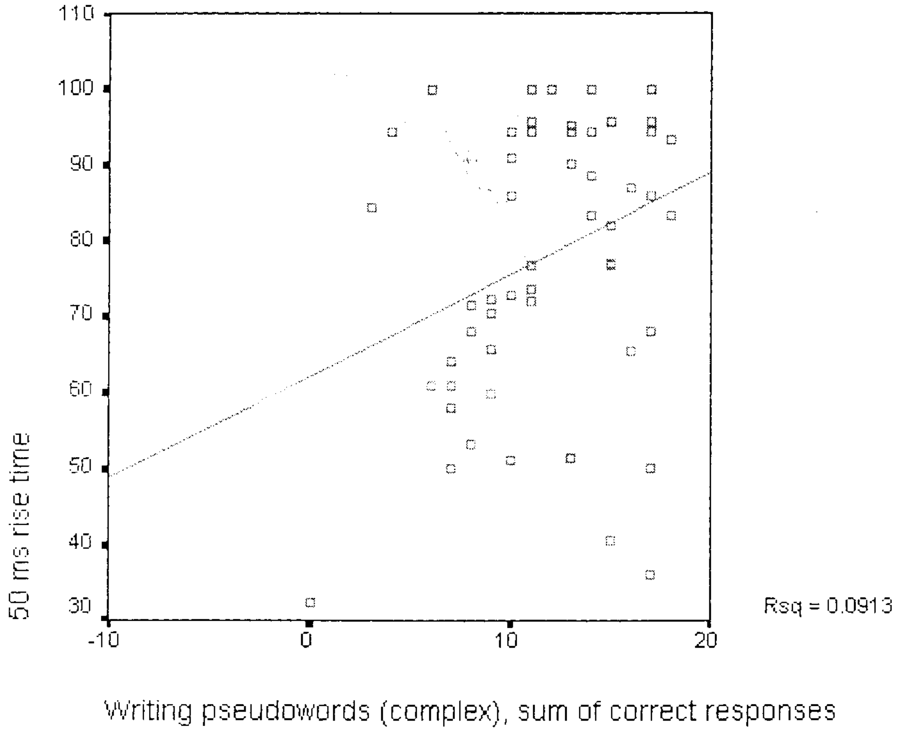

Figure 3. Scatterplot of 50 ms rise time deviant and pseudoword writing task.
The scatterplot of Figure 6. shows the relationship between the 50 ms rise time deviant and the pseudoword spelling task.

The rise time deviants correlated significantly with each other as did the duration deviants. The different deviant types had connections that can be seen in Table 6. The R-square value was 13,4 %.

Table 6. Correlation between the different deviant types. n. s. = non-significant.

	50 ms rise time	70 ms rise time	90 ms rise time
85 ms duration	n.s.	n.s.	n.s.
75 ms duration	r = 0.373 p = 0.005	r = 0.460 p = 0.000	r = 0.352 p = 0.008
65 ms duration	r = 0.404 p = 0.002	r = 0.518 p = 0.000	r = 0.428 p = 0.001

3.5 Discussion

The detection of rise time was significantly correlated to the pseudoword spelling task but not to reading comprehension. The detection of duration deviants failed to show this correlation pattern. This would suggest that stimuli with longer rise times are not perceived as shorter than the standard used here although the detectable length is shorter. Also this finding shows that attention, concentration or other such intervening variables could not explain the connection as it is present only in the rise time detection.
The effect of rise time to stimulus onset detection is small. The correlation of this study and Loveless & Brunia's (1990) article, where two different rise times were used to see the effects to N1

some data on the effects of ISI to rise time detection in stimulus pairs we wanted to see the effect on stimulus trains. Three different ISIs were used for that purpose. Also, an unresolved question was whether the steady state of the stimulus could be used as a cue in rise time detection. For this purpose we had two conditions where we either changed the steady state according to the rise time and kept the duration constant or kept the steady state the same and lengthened the stimuli by the duration of the rise time.

4.1 Subjects

The subjects were 20 (18 female, 2 male) psychology undergraduate and graduate students. The participants were voluntary subjects from a psychology course or were voluntary subjects recruited from employees of the Department of Psychology.

4.2 Stimuli

The stimulus trains were divided into two categories: those to which the rise time was included in the 100 ms length of the stimulus and those where the rise time was added to the length of the stimuli and thus keeping the steady state always the same. Both of these categories had three blocks that had different ISIs (onset to onset). The ISIs were 350 and 250 ms and depending on the length of the stimuli either 150 (rise time included) or 200 ms (rise time added to length). The deviants were either rise times (25 or 50 ms) or intensity changes (75 or 50 % of the maximum intensity level), see Figure 7. Three blocks with different ISIs were presented each consisting of 60 trials. Half of the trials had a deviant sound.
The DinoPest (see below) rise time test had standard sounds of 700 ms in length with rise time of 20 ms. The deviants started from 300 ms rise times and got closer to the standard on a logarithmic scale.

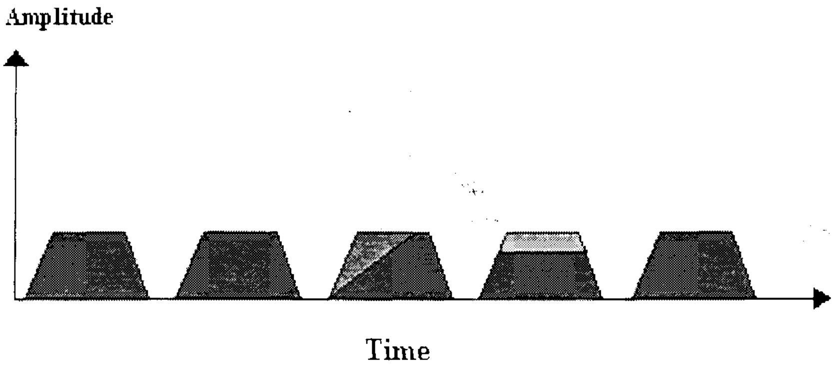

Figure 7. Illustration of the stimuli used in experiment III. Difference between standard and deviant stimuli are shown in different colour.

4.3 Procedure

Students of the Department of Psychology performed several individual tests (two rise time, P-centre, two reading and a temporal order judgement tasks). One of the rise time tests was the same as before. The other rise time test was done with DinoPest program developed by Dorothy Bishop that adaptively seeks the just noticeable difference in an ABX paradigm where a different sound had to be detected among three sounds presented. The program also gives feedback during the test. P-centre test was a categorisation task adaptively seeking the category boundary and slope. The reading tests were error searching and word division tasks from the Chaintest –battery and subjects had 20 seconds to read the words. The temporal order judgement task had a barking sound and a car horn sound and the subjects had to decide which one they heard first.

4.4 Results

Including or excluding the rise time in the overall stimulus length had no systematic effect on their detection. The only significant effect was on the 50 ms rise time detection with the shortest ISI (t-test, $t = -2.529$, $p = 0.048$) when the steady state of the stimulus was constant and when it changed. Varying the ISI had a clear effect on the rise time detection and a smaller effect on the intensity deviants, see Table 7. The ISI effects and the deviancy effect can also be seen from Table 6. The distribution of the 50 ms rise time deviant with 250 ms ISI can be seen from Figure 8.

Table 6. Means and standard deviations of the test variables. Auditory test variables are calculated from percent values. Word division and error detection values are number of items done within the time limit.

	Mean	Standard deviation
75 % intensity deviant, 150/200 ms ISI	83.0	15.93
50 % intensity deviant, 150/200 ms ISI	82.0	29.66
50 ms rise time, 150/200 ms ISI	77.0	24.52

25 ms rise time, 150/200 ms ISI	31.0	26.73
75 % intensity deviant, 250 ms ISI	91.0	9.12
50 % intensity deviant, 250 ms ISI	91.0	18.89
50 ms rise time, 250 ms ISI	78.0	24.19
25 ms rise time, 250 ms ISI	50.5	25.85
75 % intensity deviant, 350 ms ISI	93.5	9.33
50 % intensity deviant, 350 ms ISI	94.0	14.65
50 ms rise time, 350 ms ISI	94.0	11.42
25 ms rise time, 350 ms ISI	55.5	28.56
Word division	16.50 00	4.6169
Error detection	9.600 0	2.7796
Pseudo-word spelling % correct	96.83 25	4.1848

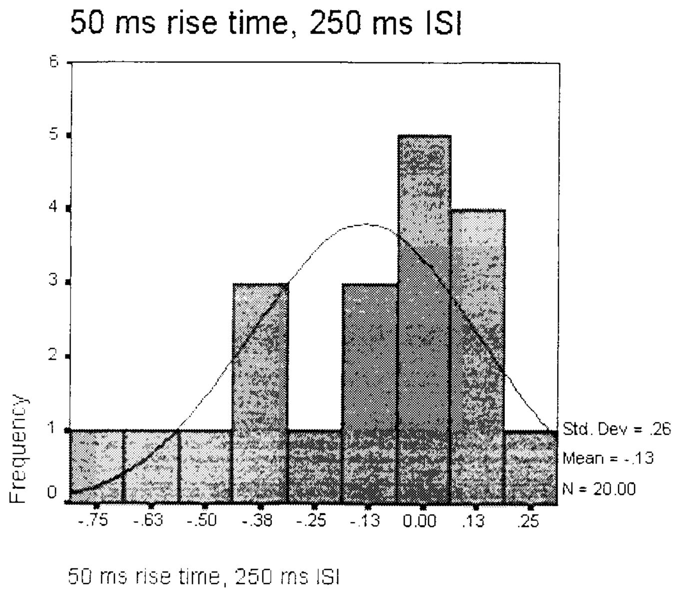

Figure 8. The distribution of the 50 ms rise time deviant with 250 ms ISI. Correct detections from standard scores.

Table 7. Effects of ISI on detection of rise times and intensities.

Stimuli	T-test result
50 ms rise time, 150/200 ms ISI vs. 350 ms ISI	t = -2.253, p = 0.036
50 ms rise time, 250 ms ISI vs. 350 ms ISI	t = -2.100, p = 0.049
25 ms rise time, 150/200 ms ISI vs. 250 ms ISI	t = -2.799, p = 0.011
25 ms rise time, 150/200 ms ISI vs. 350 ms ISI	t = -2.770, p = 0.012
75 % intensity, 150/200 ms ISI vs. 250 ms ISI	t = -2.529, p = 0.020
75 % intensity, 150/200 ms ISI vs. 350 ms ISI	t = -2.155, p = 0.044

Comparing the rise time test to other tests done revealed only a few significant correlation as seen in Table 8. See figures 9, 10, and 11. for scatterplots of the correlated rise time and reading task variables.

Table 8. Correlation between different tests and stimuli. N = 20 except in the P-centre N = 19 and the dog/car TOJ test N = 12 (due to lost data).

Test	Dino: percent correct from 4th reversal	Word division test	Error detection	P-centre boundary value	Dog/car TOJ boundary value
Word division	r=0.542 p=0.014	n.s.	r=0.726 p=0.000	n.s.	n.s.
Error detection	r=0.502 p=0.024	r=0.726 p=0.000	n.s.	n.s.	n.s.
50 % intensity 150/200 ms ISI	n.s.	n.s.	n.s.	R=0.632 p=0.004	r=0.731 p=0.007
50 % intensity 250 ms ISI	n.s.	n.s.	n.s.	R=0.632 p=0.004	n.s.
50 % intensity 350 ms ISI	n.s.	n.s.	n.s.	R=0.693 p=0.001	n.s.
50 ms rise time 250 ms ISI	n.s.	r=0.448 p=0.047	n.s.	R=0.693 p=0.0001	n.s.

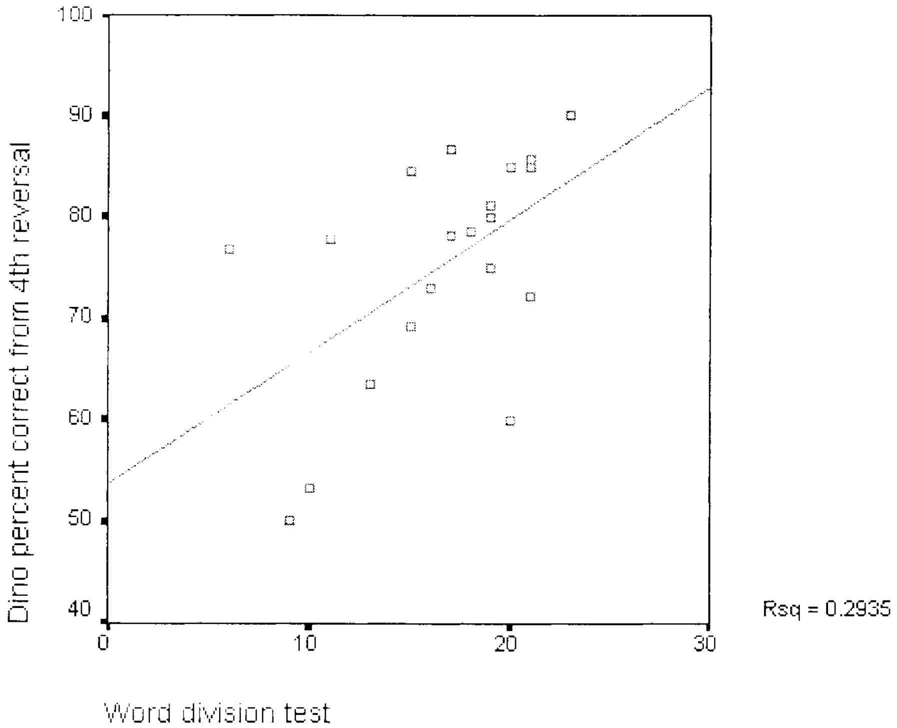

Figure 9. Scatterplot of the DinoPest discrimination task and the word division test.

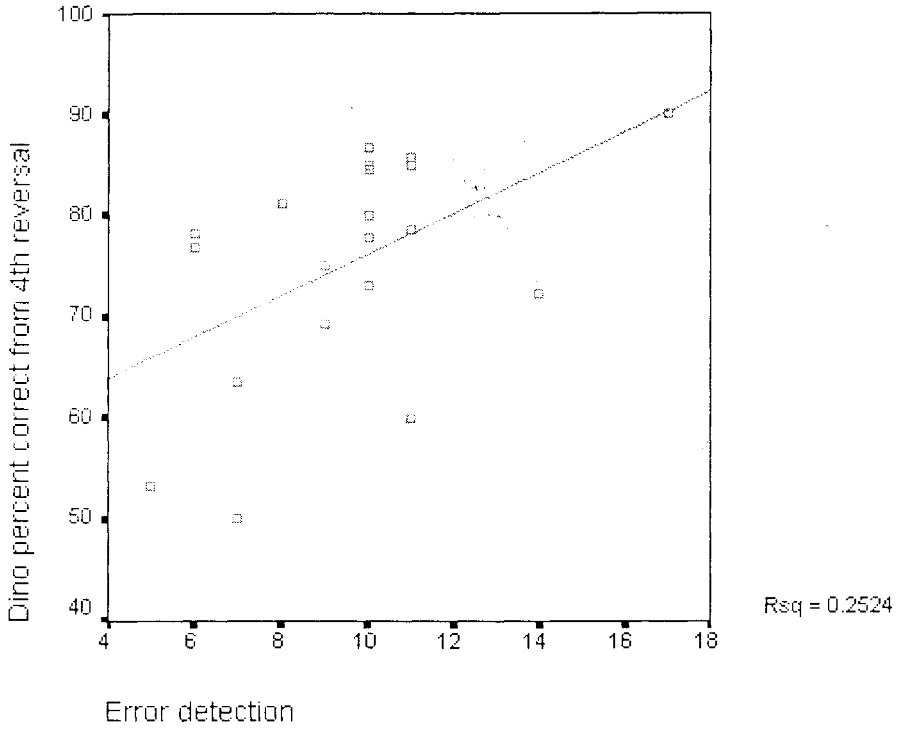

Figure 10. Scatterplot of the DinoPest discrimination task and the error detection test.

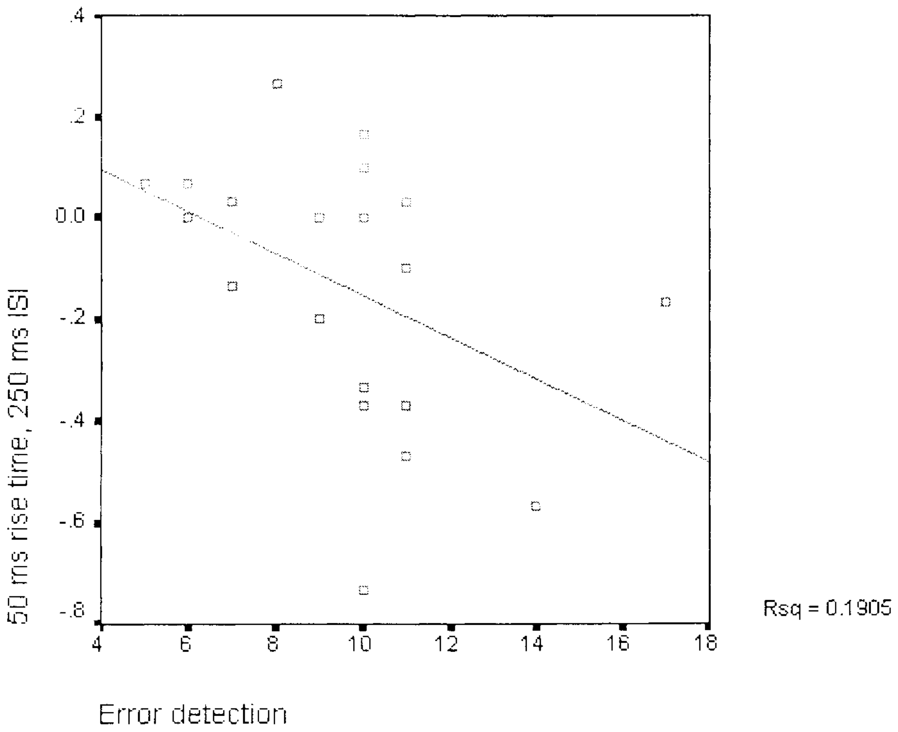

Figure 11. Scatterplot of the 50 ms rise time deviant with 250 ms ISI and the error detection test. Notice that the rise time variable is number incorrect items (z-score) and not number of correct items.

Regression analysis using the enter method showed that the rise time detection tasks (50 ms rise time with 250 ms ISI and the dino test percent correct after 4^{th} reversal) together accounted for 50,1 % (29,3 % and 20,7 %, respectively) of the variation in the word division test ($t = 3.201$, $p = 0.005$ for DinoPest task, $t = -2.663$, $p = 0.016$ for 50 ms rise time).
The detection of intensity deviants did not correlate with any of the language tests. The correlation between the detection of rise time and intensity deviants can be seen in Table 10. With an ISI of 150/200 ms the 25 ms rise time deviant was correlated to both 75 and 50 % intensity deviants. When the ISI was 350 ms the 75 % intensity deviant had a significant correlation to both 25 and 50 ms rise time deviants.

Table 10. Significant correlation between rise time and intensity deviants. N = 20.

	75 % intensity, 150/200 ms ISI	50 % intensity, 150/200 ms ISI	75 % intensity, 350 ms ISI
25 ms rise time, 150/200 ms ISI	r = 0.513 p = 0.021	r = 0.512 p = 0.021	n. s.
50 ms rise time, 350 ms ISI	n. s.	n. s.	r = 0.612 p = 0.004
25 ms rise time, 350 ms ISI	n. s.	n. s.	r = 0.502 p = 0.024

4.5 Discussion

The rise time detection was again significantly correlated to language skills and the detection of intensity change was not. This can be interpreted to show that rise time and intensity detection are not the same thing and that only rise time has a relevance to reading skills. There was only four significant connections between rise time and intensity deviants. These showed that with the shortest ISI the harder to detect rise time was connected to both intensity deviants and with the longest ISI the harder to detect intensity deviant was correlated to both rise times. ISI seems to be the common factor with the correlated stimuli.
The lack of systematically significant differences in detecting the rise time when the steady state of the stimulus was constant and when it changed according to the rise time, shows that the steady state is not used as a cue in this perception task.

Although, t-tests showed differences in performance due to ISI it cannot be said from the single correlation to the reading skills that ISI would be the cause for the connection. From Table 8 can be seen that only one correlation to the reading tests was found.

Again the 50 ms deviant had highest (and only) correlation to speech perception. Perhaps the lack of correlation to the detection of the more difficult deviant was due to the fact that most of the subjects did not perceive them causing a floor effect.

5. Experiment IV

We chose the ISI to be 200 ms from the results of the previous study but shortened it due to time limitations in the testing sessions. Because of the same reason only 60 trials were presented as that seemed to be enough in Experiment III although in the two first studies 180 trials were the minimum number used. The aim of this study was to see if a group test would show the same connections between reading skills and rise time detection and how rise times of different lengths are connected to language skills.

5.1 Subjects

Subjects were 145 (127 boys, 14 girls, 4 missing data) vocational school students from two different schools. Only 123 of the students participated in all of the tests. The subjects were from 13 different classes and were not selected in any way before hand.

5.2 Stimuli

The stimuli were as in Experiment III except that the deviant rise times were 25, 35, 45, 55 and 65 ms. The standard had 10 ms rise time as before and the ISI was 200 ms (onset-to-onset). The inter-trial interval (onset-to-onset) was 3000 ms. All stimuli were again 100 ms in length.

5.3 Procedure

A group test battery was performed to 150 vocational school students. Tests included rise time detection, fast word recognition, pseudo-word and general literacy assessment tasks. The same students had earlier carried out an extensive test battery of reading tests that included error detection in written words, word division (both from the Chaintest –battery), non-word and word spelling and reading comprehension tasks.

In the fast word/non-word recognition task words and non-words were shown in a screen with a data projector. The words/non-words were displayed for 60 or 80 ms and then a mask would appear (the mask was #####). The subjects had to choose from six different alternatives the correct word shown to them.

There were three pseudo-word tasks. In the first one subjects had to decide if the two words they heard were the same or different. In the second test a model word was played twice and after that three alternatives were played from which the one most similar to the model word had to be picked. In the last pseudo-word task a word was played twice and from four written alternatives the matching one had to be found. All of the pseudo-word tasks had either a double consonant or vowel as the target to be attended to.

In the rise time test six practise trials were presented before the actual test was performed. The test consisted of 60 trials.

In the first school the sound level was about 65 dB and did not vary significantly in the room. In the second school the level was 70 dB and as the room was narrow and long the sound decreased to the back of the room by three decibels.

5.4 Results

The means and standard deviations can be seen from Table 11. and the distribution of the 55 ms rise time deviant from Figure 12.

The composite d' score consisting of all the rise time deviants correlated significantly with the non-word spelling task ($r = 0.185$, $p = 0.040$). Of the individual deviants 55 ms and 65 ms rise times were the only ones that correlated with the non-word spelling ($r = 0.238$, $p = 0.008$; $r = 0.190$, $p = 0.035$). In addition the 55 ms rise time deviant correlated with the word division test and word spelling task. The R^2 values of the 55 ms rise time detection to non-word spelling task was 5.8% and the corresponding value to the word division task 4.6 %. Of the tests that were done on the same day only fast non-word recognition showed connection to rise times, see Table 12. The scatterplots of the 55 ms rise time deviant and the non-word spelling and word division tasks can be seen in Figure 13. and 14.

Table 11. Means and standard deviations of the variables. Rise time mean values are percent of correct items out of 6. For the spelling tasks 17 was the maximum result.

	Mean	Standard deviation
Combined rise time d'	-0.038	1.615
25 ms rise time	43.62	24.74
35 ms rise time	60.29	28.15
45 ms rise time	76.38	22.07
55 ms rise time	83.62	21.17
65 ms rise time	86.86	17.06
Reading comprehension	29.48	11.60
Word division	47.13	15.25

Error searching	51.18	22.69
Word spelling	15.21	2.280
Non-word spelling	13.83	2.980
Literacy test	72.88	10.56

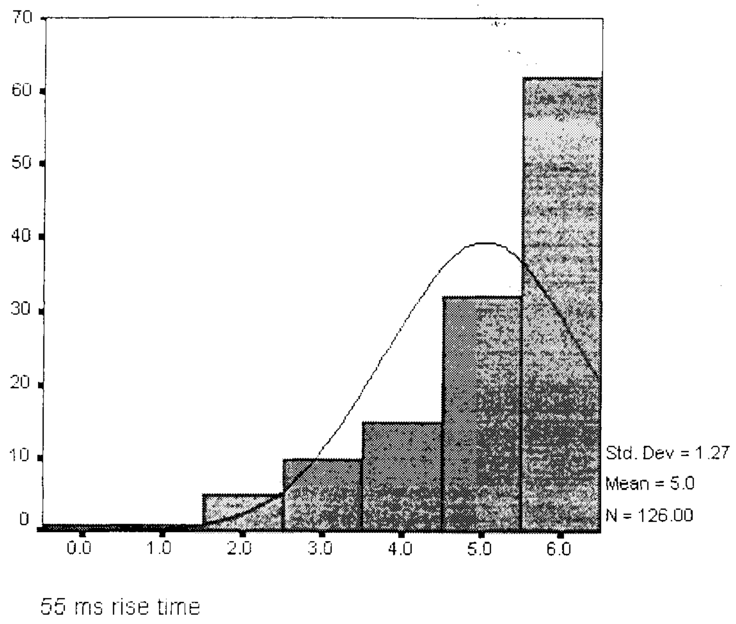

Figure 12. The distribution of the 55 ms rise time deviant. Correct responses out of 6.

Table 12. Rise time correlation to language tests. N = 123.

	D' composite	55 ms rise time	65 ms rise time
Word division	n. s.	r = 0.216, p = 0.017	n. s.
Word spelling	n. s.	r = 0.224, p = 0.013	n. s.
Non-word spelling	r = 0.185, p = 0.040	r = 0.238, p = 0.008	r = 0.190, p = 0.035
Fast non-word recognition	n. s.	r = 0.178, p = 0.050	n. s.

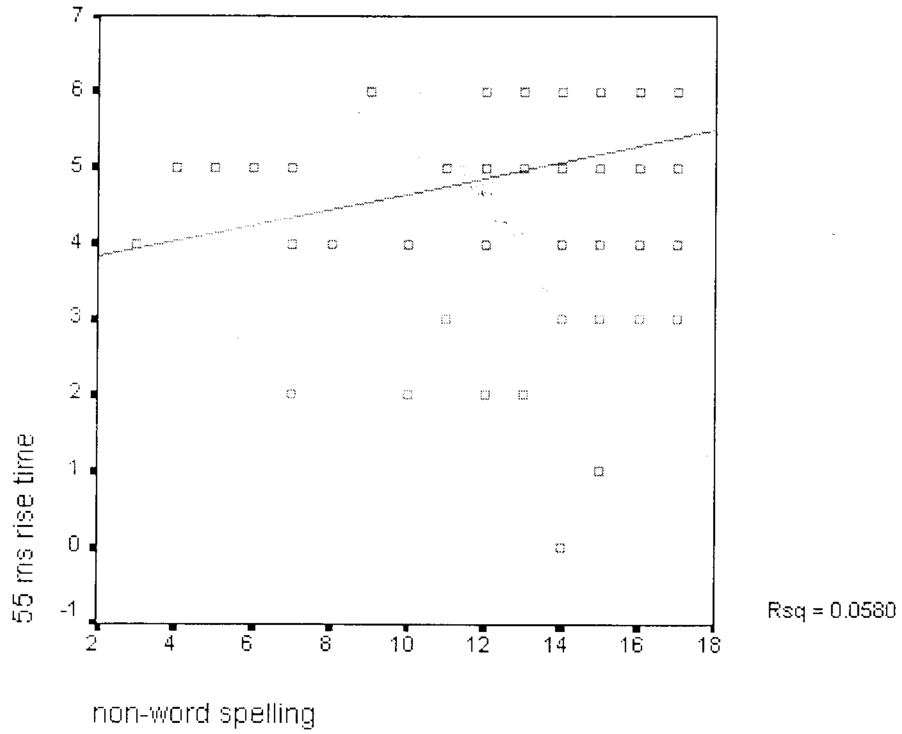

Figure 13. Scatterplot of the 55 ms rise time deviant and the non-word spelling task.

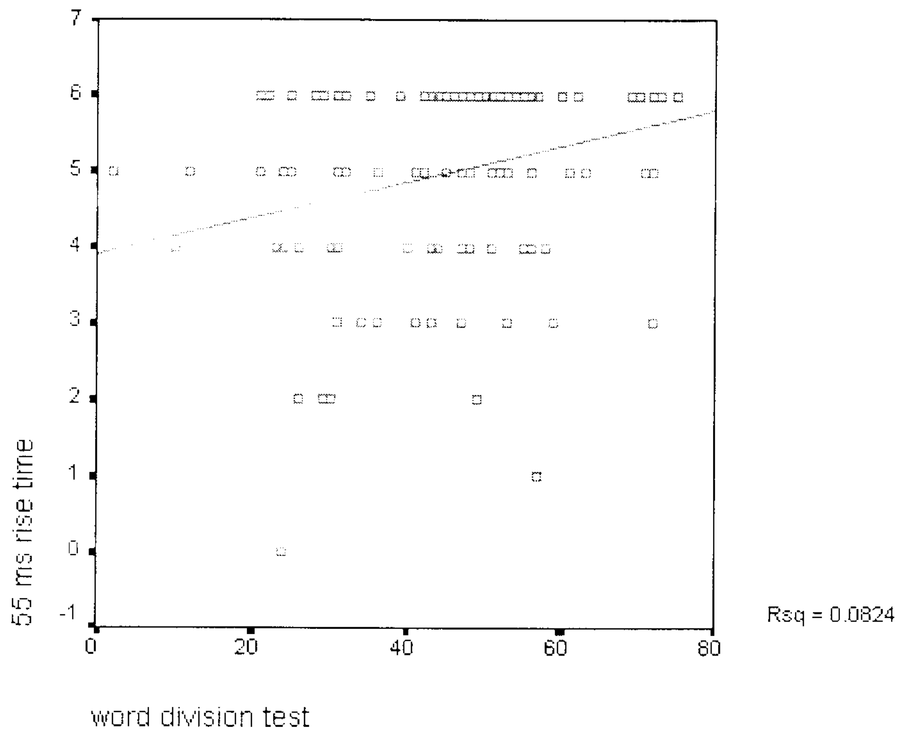

Figure 14. Scatterplot of the 55 ms rise time deviant and the word division test.

5.5 Discussion

Correlation to language tests once more confirmed the connection between speech perception, reading skills and rise time detection. Reading comprehension test showed no correlation, as in experiments II and IV and confirms that this acoustic sound detection test does not just measure concentration ability or intelligence i.e. a general ability reflected in understanding written text. The correlation was highest for speech perception (spelling tasks) as expected. The word division test measures mainly reading speed and thus this result is in accord with the experiment I.

The correlation to fast non-word recognition was unexpected. This could reflect a different strategy in detecting the non-words than words. If the subjects had to use phonological representations to remember the non-word shown to them the same ability could be seen in rise time detection. And the task measures actually reading speed and in that way the correlation is understandable. The fast word recognition was close to significance ($r = 0.163$, $p = 0.072$) and would thus support the latter hypothesis.

6. General Discussion

The first experiment showed that there could be some connection between speech perception and rise time perception. The correlation ($r = 0.552$, $p = 0.006$) was high and significant. Experiment II confirmed the finding. Experiment III showed a connection to reading ability in a rather homogenous group, see Table 13 for a summary of the experiments. In experiments II and III the detection of duration and intensity failed to show an association to language tests which suggests that rise time detection is a separate phenomenon from these, even though rise time is a change of intensity over time.

Experiments II and IV were group testing in large groups. These test scores are not as reliable as those of individual tests but they allowed collection of a lot of information in a short time. Also to be noted from the results in Experiment IV is that there were only six repetitions of each deviant stimuli. This might increase the error variance like momentary lapse of concentration and outside noises.

Table 13. Summary of the experiments. Best deviant is the rise time of the deviant stimuli that provided the best correlation. Correlation is to reading ability or speech perception.

Experiment	Subject group	Design	Best deviant	ISI (onset-to-onset)	Correlation
I	Adult dyslexics (N=23)	pairs	80 ms	500 ms	$r = 0.552$, $p = 0.006$
II	8-year-olds (N=56)	trains	50 ms	150 ms	$r = 0.367$, $p = 0.005$
III	University students (N=20)	trains	50 ms	250 ms	$r = 0.448$, $p = 0.047$

IV	Vocational school students (N=123)	trains	55 ms	200 ms	$r = 0.238$, $p = 0.008$
"best" parameters		trains	50 – 55 ms	250 ms	$r > 0.3$, $p < 0.05$

Next we will discuss possible causes of the results. First rapid processing of stimuli then temporal integration window and fuzzy phonological representations are considered. Also sluggish attentional shifting, magnocellular theory, summation of action potentials and amplitopic and tonotopic maps of the cortex will be discussed.

The stimuli were presented in a rapid sequence. That alone could have produced active inhibition or refractoriness in the neurones. In Experiment I the masked word reading task had a high correlation to rise time detection and this would support the above mentioned reason as backward masking is related to rapid stimulus processing. But rapid processing deficit would not have produced a higher correlation with the longer ISI as was the case in Experiment I and it would have affected all the deviant types similarly.

One causal factor explaining these results could be impaired temporal processing. If rise times are perceived as dynamic changes within stimulus this would be a logical answer. The impaired rhythm detection (Alcock et al., 2000) as well as auditory illusion (Hari & Kiesilä, 1996) and segregation (Helenius, 1999), AM and FM studies (McAnally et al., 1997; Menell & McAnally, 1999; Lorenzi et al., 2000), rapidly presented stimuli (Tallal, 1980) and interval detection (Rousseau et al., 2001) all hint at a temporal aspect. This aspect could be related to the temporal integration window (Yabe et al., 1998). In the Yabe et al. study (1998) the length of the temporal integration window was estimated to be shorter than 175 ms. If the window would be longer in people with dyslexia it should be over 250 ms long to explain the results in the present experiments. Subjects with dyslexia fused sounds together at SOAs of 210 ms compared to normal readers' 130 ms in a stream segregation study by Helenius et al. (1998). This could be taken as evidence of a longer integration window for people with dyslexia. Impaired frequency modulation detection at high rates could be explained also with the longer window. Why then is detection of frequency modulation depth at 2 Hz also is impaired? This cannot be interpreted by longer temporal integration window as the window would have to be over 500 ms long. And in relation to the present experiments the temporal integration window would affect also the duration and intensity deviants in Experiments II and III. Rise times could be connected to rhythm detection as suggested by P-centres. And rhythm detection and production was shown to be impaired in Alcock et al's (2000) study among participants with specific language impairment compared to age mates without language difficulties. But what mechanisms underlie rhythm detection?

Another possibility is that as for example p and b are defined by different voice-onset-times in which rise time is a major part, the phonological representations remain fuzzy and categories of different phonemes are difficult to form as Lorenzi et al's (2000) study showed. Impaired rise time detection may not alone be sufficient to cause dyslexia but it could be one part of it. The finding that subjects with dyslexia are better at discriminating sounds within categories (Serniclaes et al., 2001) does not support this notion but Serniclaes et al. used a paired stimuli discrimination task that does not tap into categories per se.

Hari and Kiesilä (1996) describe an experiment where subjects with dyslexia heard an auditory illusion with ISIs of 250 – 500 ms when controls did not perceive it at ISIs over 120 ms. The result could be interpreted so that top-down processes are affecting the earlier stimulus representations in the echoic memory. Hari and Renvall (2001) propose this top-down process to be sluggish attentional shifting. In these experiments if attention can not be moved from one stimulus to the next fast enough it could lead to impaired discrimination of rise times but in Experiments II and III it should have affected duration, intensity and rise time deviants equally and the correlation to language skills show that this was not the case. Even though the subjects did not have dyslexia in all of the present experiments the same kind of mechanisms (such as sluggish attention) could be supposed to affect these results.

Amplitude modulation at 2 Hz did not differentiate normal readers and controls but 20 Hz AM did. This is in contrast to the frequency modulation of 2 Hz where subjects with dyslexia performed worse than controls (Witton et al., manuscript). 20 Hz AM would correspond to 25 ms rise time that did not have the highest correlation in the present experiments.

In a review by Radionova (1993) studies by Gershuni of the effects of rise time to auditory nerve summed responses N1 and N2 were examined. Desynchronization of single nerve fibers appears as rise time is made longer. If the magno cells in the thalamus are disordered and smaller in people with dyslexia would they need a more coherent and synchronous signal to decipher speech elements from the signal and thus cause difficulties in temporal perception and voice-onset-time and formant transition detection. Gershuni's finding is in accord with Loveless and Brunia's (1990) study with reduced amplitude of N1 components with long rise times. Näätänen (1992) suggests that component 3 of the N1 response is generated by the reticular system through ventral lateral (VL) nucleus of thalamus in the frontal motor and premotor cortex. In addition to the reticular formation the VL nucleus receives input from the cerebellum (Kolb & Whishaw 1996). This would all fit nicely to the magnocellular theory as both thalamus and cerebellum are considered to be important for the temporal processing of stimuli. If in rise time detection the component 3 of N1 response is somewhat critical it could be that in people with dyslexia it would be abnormal, that is probably smaller in amplitude and longer is latency. But it is unlikely that motor and premotor cortex would be critical for speech perception and thus this is pure speculation.

Heil and Neubauer (2001) demonstrated that the first action potential spike for the beginning of a sound stimuli was dependent on the delays in the conduction through the middle and inner ear, the speed of the nerve fiber measured and on the integral of the amplitude envelope. That is both the overall stimulus amplitude level and rise time determine how fast the auditory nerve fibers react to stimuli. If the rise time of a stimulus is long and the overall amplitude high the nerve fibers will react as fast as when the rise time is short and overall amplitude low. If this aspect of neural responses would be impaired in dyslexia it would have to be in the summation of the action potential on the cell membrane before it reaches the critical value of releasing the action potential. This would mean that if the overall intensity value changes the detection would be unimpaired as the action potential is launched at the beginning of the stimuli but when a long rise time is presented "normal" people would detect it faster than dyslexics because of summation of the action potential. In event related potentials the differences between these populations would probably be seen very early and would perhaps manifest in longer latency in the overall waveforms.

If the auditory cortex has an amplitopic organisation in addition to tonotopic organisation (Näätänen, 1992) rise time detection could be regarded as a function of how fast the brain can form a coherent representation of the sound stimuli. The amplitopic representations meaning that different neuronal columns activate as different amplitude level stimuli are presented. At least in the macaque monkey's auditory cortex neurones that respond differently to different intensity stimuli have been found (Recanzone et al., 2000). If the formation of the representation takes a long time then the next incoming stimuli might disrupt the processing of the previous stimuli. Another option would be that the temporal information obtained is so unclear that the representation is not constructed in the correct order. Thus rise times that have a fast changing amplitude over time would be especially hard to reconstruct. The same should then be true for frequency modulations as McAnally & Stein (1997) and Menell & McAnally (1999) have shown to be the case. Still it would be interesting to see how simple frequency sweeps would be detected.

In order to examine the mentioned hypothesis of the possible connections between rise time detection and reading skills both ERP and behavioural experiments should be done. If the refractoriness of the N1 wave is greater in people with dyslexia all rapidly presented stimuli should be difficult for them and this should be seen in the ERPs as diminished N1 amplitude. On the other hand as these studies and others (Baldeweg, 1999, found no difference in duration detection between dyslexics and controls) have shown that not all stimuli are connected to reading ability as the above mentioned hypothesis would suggest. It could be then that as rise times increase the refractoriness of the neurones (Radionova, 1993) that this element would produce the effect more readily.

Another related hypothesis was that of forming a clear representation of temporally changing stimuli requiring different neuronal populations to fire and this would be impaired in people with dyslexia as in the magnocellular theory. In tonotopic and amplitopic maps of the auditory cortex different neurones fire for different frequencies and amplitudes (Näätänen, 1992) and if the timing information of these different neurones is inaccurate the formation of an exact representation of the auditory stimulus with temporally changing features is impossible. Or the neurones in these maps are not as specific as they should be in that they fire to neighbouring frequencies/amplitudes as well but less than to their own. This would lead to more fuzzy representation of a pitch/amplitude sweep and of an instant pitch/amplitude change. And as that seems not to be the case in Experiment III with intensity detection the integration of temporally changing features is a more probable causal factor. This should be seen in behavioural performance of rise time and frequency sweep detection. In ERPs a smaller mismatch negativity and perhaps a larger N1 could be expected to reflect the affected brain processing difference among individuals with dyslexia.

There are evidence from amplitopic representation of sound intensity at least in the monkey brain (Recanzone et al., 2000) and some evidence in the human brain (Lockwood et al., 1999). Dynamic changes in both frequency and amplitude of sounds seems to be related to reading and dyslexia (McAnally & Stein 1997, Witton et al., manuscript, present studies). It could be possible that these tonotopic and amplitopic areas of the brain are abnormal in dyslexics and detecting AM and FM changes gives important temporal information that is not being detected by dyslexics as easily as normal readers. Or perhaps if these areas aren't abnormal per se the mechanisms that form a coherent representation of the sound are abnormal.

These studies did not give insights as to what kind of neuronal mechanisms might underlie rise time detection, other than its apparent dissociation from sound onset and intensity detection in these particular studies. What can be concluded is that rise time detection is connected to reading and writing skills. Further studies are needed to answer how and why.

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