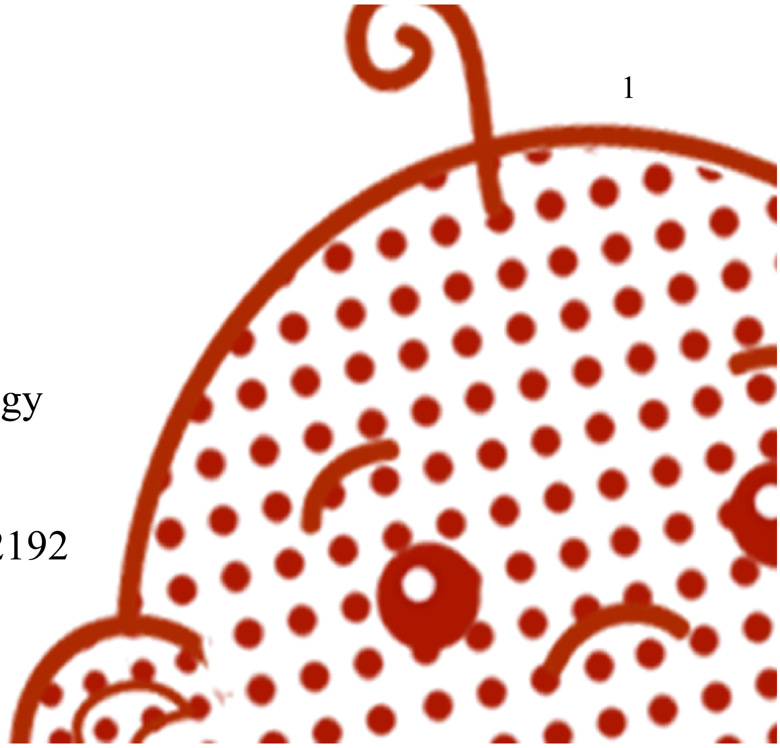

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Implicit learning in infants with a familial risk of dyslexia: the effects of age and length of training

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ABSTRACT

The current study is a follow-up study on the work of Kerkhoff, De Bree, De Klerk & Wijnen (2011; in press) in which the hypothesis was tested that developmental dyslexia is (partly) caused by a deficit in implicit sequential learning. With the help of a head-turn-experiment it was investigated whether 18-month-old infants at familial risk of dyslexia can track non-adjacent dependencies in an artificial language. A deficit in implicit learning can hinder the processing of such dependencies. For this experiment an artificial language is used to test the tracking of these NAD's, in the form of a-X-c, b-X-d or a-X-d, b-X-c, with fixed first and third elements and 24 different X elements. Family risk (FR) and typically developing (TD) infants were exposed to one of two novel languages containing these dependencies. The results revealed that only the typically developing infants could discriminate between grammatical and ungrammatical sentences. This was in contrast with the results of the family risk infants, who showed no discrimination between the grammars. To test whether the FR group's poor performance was due to a developmental delay, the current study exposed a group of 24-month-old FR-infants to the same task (Experiment 1). To investigate whether these children might benefit from an increased exposure to the artificial language, a pilot study also examined whether 18-month-old TD and FR infants are able to discriminate between the grammars after a prolonged familiarization phase (Experiment 2). The results show no evidence that the 24 month-old FR group is sensitive to NAD's. This could be evidence for a delay in implicit sequence learning of at least six months. Furthermore, the TD infants in the pilot experiment showed a trend towards an unexpected change from a novelty preference to a familiarity preference.

Keywords: dyslexia, implicit learning, artificial language learning, non-adjacent dependencies, extended familiarization phase, developmental delay

Introduction

Dyslexia is a developmental language disorder, which results in unexpected problems in reading, writing and spelling, despite a normal intelligence and social level (Démonet, Taylor, Chaix, 2004). Approximately 4% of Dutch school aged children experience difficulties in quick and accurate reading and spelling, and are diagnosed with dyslexia (Van der Leij, 2004). Dyslexia is a heritable disorder. Genetic research has shown that the chance of suffering from dyslexia increases when one of the parents is dyslexic, from a chance of 5% - 10% when no parent is dyslexic, to a chance of 30% - 60% (Olson, 1999). Given the fact that the actual symptoms of dyslexia – reading and spelling problems – only appear when the child starts to learn reading and writing, it seems impossible to study the early language development in dyslexia in infants and preschool children. However, since the genetic risk of dyslexia is high, it is possible to examine the early language development in at-risk infants and preschool children. Many studies have shown delays in the early language development from infants at familial risk of dyslexia (Scarborough, 1990; Snowling, Gallagher & Frith, 2003; Van Alphen, De Bree, Gerrits, De Jong, Wilsenach & Wijnen, 2004; Koster, Been, Krikhaar, Zwarts, Diepstra & Van Leeuwen, 2005) such as processing of speech input, phonological and morphological skills, productive vocabulary, pronunciation accuracy and use of grammatical morphology. For instance, De Bree (2007) showed that speech production, word stress production, and non-word repetition are potential linguistic precursors of dyslexia.

Dyslexia is often found to be comorbid with other developmental disorders such as attention-deficit/hyperactivity disorder (ADHD) (Gilger, Pennington, DeFries, 1992; Nicholson & Fawcett, 2007; Germanò, Gagliano, Curatolo, 2010), specific language impairment (SLI) (McArthur et al., 2000; Bishop & Snowling, 2004; Nicholson & Fawcett, 2007), developmental coordination disorder (DCD) (Visser, 2003, Nicholson & Fawcett, 2007), and autism (Nicholson & Fawcett, 2007; Bishop, 2008). For example, dyslexia has a chance of 11% to 40% to be comorbid with ADHD (Shaywitz et al., 1994). Moreover, at least 50% of the dyslexic children show early in the development motor problems (Nicholson & Fawcett, 2007). The considerable overlap between disorders makes it difficult to create diagnostic boundaries between them.

First, the theories of dyslexia are discussed, which are followed by the reason for this pilot and the present research questions. A lot of research has been done with regard to dyslexia, but the underlying cause of this disorder is still not clear. There are different theories about the causal factor(s), and these theories are described below.

Phonological Deficit Theory

The first hypothesis discussed is the 'Phonological Deficit Hypotheses'. This theory implicates "a deficit of direct access to, and manipulation of, phonemic language units retrieved from long-term declarative memory" (Démonet et.al., 2004, p. 1452). A phoneme distinguishes one word from another and is the smallest unit of speech, for example *tak* 'branch' versus *dak* 'roof'. This theory can explain the reading difficulties in dyslexics from the fact that learning the correspondence between letters and speech sounds (grapheme-phoneme correspondence) will be affected if speech sounds are poorly represented, stored, or retrieved (Velluntino, 1979, Snowling, 1981, Ramus, Rosen, Dakin, Day, Castellote, White, Frith, 2003). According to De Bree (2007, p. 9) "poor phonological representations lead to slow literacy development, poor generalization of word reading skills to non-word reading, and poor spelling development". The phonological theory is limited by the fact that it cannot explain why there are a significant proportion of dyslexics who suffer from sensory and motor disorders.

The Cerebellar Theory

Secondly, there is the 'cerebellar theory' or 'automaticity theory' (Nicolson & Fawcett, 1990; Nicolson, Fawcett & Dean, 2001). The cerebellum is found to be mildly dysfunctional in children and adults with dyslexia. Prior research with children demonstrated that the volume of the cerebellum is smaller for dyslexic children as compared to controls (Rae et al., 1998; Brunswick, McCrory, Price, Frith & Frith, 1999; Brambati et al., 2004; Brown, Eliez, Menon, Rumsey, White & Reiss, 2001; Finch, Nicholson & Fawcett, 2002; Rae et al., 2002; Eckert, Leonard, Richards, Aylward, Thomson & Berninger, 2003; Eckert, 2004; Stoodley & Schmahmann, 2009b,c). The cerebellum is known for its influence in motor control, hence the cerebellum is related to speech articulation. A dysfunction in articulation movements may lead to a deficit in phonological representations (Nicholson, Fawcett & Dean, 2001). A second role the cerebellum plays according to Nicolson & Fawcett (1990) is the automatisation of skills and knowledge. Automatisation of a skill is established as follows; the process "represents first the acquisition of the declarative knowledge of what should be done and then the gradual 'proceduralization' of the knowledge, changing it from declarative form to automatic “production rules” which capture the procedural knowledge of how to achieve the goal” (Nicoloson & Fawcett, 1989). Nicholson & Fawcett (1994) report that the automatisation theory predicts severe deficits for spelling, wordflash, and on dual task or blindfold balance. However, the cerebellar theory does not explain why some dyslexics have an impairment in motor functions, and some do not (Nicholson & Fawcett, 1990; Ramus et al., 2003).

Procedural Deficit Hypothesis

Finally, there is the Procedural Deficit Hypothesis (PDH). The PDH resembles the cerebellar theory, but according to the Procedural Deficit Hypothesis dyslexia and SLI can be mainly explained by brain structures connected to the procedural memory, which develop abnormal (Ullman & Pierpont, 2005; Nicolson & Fawcett, 2007). These brain structures consist of the basal ganglia, frontal cortex (in particular, Broca’s area and premotor regions), parietal cortex, superior temporal cortex and cerebellum (Nicholson & Fawcett, 2007). Functions that depend on these brain structures are linguistic (implicit phonological rules) and non-liguistic (motor) functions, which will be impaired if these brain structures are abnormal. Functions that do not depend on these brain structures are expected to remain intact, such as lexical and declarative memory (Ullman & Pierpont, 2005). The procedural memory system supports the learning of new rule-based procedures that control the regularities of language. This is also useful in other domains, such as in the learning of new skills and control of established sensori-motor and cognitive skills, such as learning to ride a bike. Sequential rule learning possesses aspects which rely on the procedural memory system, resulting in implicit knowledge. (Nicholson & Fawcett, 2007; Kerkhoff et al., in press). According to Cleeremans et al. (1998, p. 1), “learning is implicit when we acquire new information without intending to do so, and in such a way that the resulting knowledge is difficult to express”. An example of implicit learning is learning a mother language. Implicitly the child learns the grammar of the language; the child isn’t aware of learning the rules but can apply them without knowledge. This procedural (implicit) system could be involved as children with (a familial risk of) dyslexia have been found to have delays in both language development and (motor) skill learning (Kerkhoff et al., in press) Moreover, there are several studies that show neuroanatomical and functional abnormalities in the brain areas mentioned above, which are involved in procedural learning (Eckert et al., 2003; Menghini, Hagberg, Caltagirone, Petrosini & Vicari, 2006; Kerkhoff et al. in press). Vicari, Marotta, Menghini, Molinari and Petrosini (2003) and Vicari, Finzi, Menghini, Marotta, Baldi and Petrosini (2005) reported deficient implicit learning in dyslexic children with the help of a visuomotor 'Serial Reaction Time' (SRT)-task and a Mirror Drawing (MD) Test. The SRT task measures (implicit) motor skill learning and is a simple procedure in which participants follow a sequence existing of four squares which light up one-for-one on a computer screen. The sequence can be fixed or random and must be reproduced on a button-box, in which the buttons correspond to the positions on the screen. Learning about stimulus order is revealed through decreased reaction times for structured versus randomized sequences (Nissen & Bullemer, 1987). In the MD test, the children are asked to trace a line of a five pointed star while they looked at the star and their hand through a mirror. This task "involves the establishment of fast and repetitive processing of visuospatial stimuli but no acquisition of sequences" (Vicari et al., 2005, p. 1393). Vicari et al. (2003) also included an explicit SRT-task. During this SRT task the participants are aware of the present fixed sequence. Their main finding suggests that individuals with developmental dyslexia are impaired in the acquisition of implicit sequence knowledge, while there was no significant difference between the dyslexic and control groups in terms of explicit sequence learning. This supports the hypothesis of dyslexia being a procedural (or implicit) learning deficit.

The current study is a follow-up of the experiment of Kerkhoff et al. (in press). Kerkhoff and colleagues examined the hypothesis that developmental dyslexia is (partly) caused by a deficit in implicit sequential learning by investigating whether infants at familial risk of dyslexia can track non-adjacent dependencies in an artificial language.

As stated above, this study continues on the results of Kerkhoff et al. (in press). Since the PDH assumes that the procedural memory system supports the learning of new rule-based procedures that control the regularities of language, this would concern the non-adjacent dependency learning examined in the study of Kerkhoff et al. In addition, the present study will examine this non-adjacent-dependency learning in young infants as well.

Non-adjacent dependencies

Non-adjacent dependencies (NAD's) are crucial for the acquisition of grammatical patterns and categories (Kerkhoff, et al., in press). Despite the fact they are difficult to acquire, NAD's play an important role in language (Newport & Aslin, 2004; Gomez & Maye, 2005). In the English language is the 'is X-ing' pattern one of the most well known examples of NAD's (i.e. the relation between *is* and *–ing* in sentences like 'she *is* happily sing*ing*). Variant linguistic material (such as *happily sing-*) may separate the invariant dependent elements *is* and *ing.* According to Gomez and Maye (2005, p. 184) "learning dependencies between nonadjacent words and morphemes is important in acquiring the (morpho)syntax of a language".

Kerkhoff et.al. (2011; in press) based their experiment on a head-turn experiment by Gomez (2002) and Gomez and Maye (2005). In the study of Gomez (2002) infants were exposed to one of two novel artificial languages containing a NAD grammar. The artificial languages existed of a pattern consisting of three non-words, in which the first and last word were fixed, and the middle word (X word) existed of 24 different words, which were the same for both languages. The pattern for the first language was a-X-c and b-X-d (e.g. *pel wadim jic* and *vot kicey rud*), wereas the second language consisted of the pattern a-X-d and b-X-c (e.g. *pel wadim rud* and *vot kicey jic).* Since the X-words were the same for both languages, the dependency between the first and last words was the key to discover the pattern (Kerkhoff et al., in press). The experiment consisted of a familiarization phase and a test phase, using the head-turn preference procedure (Kemler-Nelson et al., 1995). The original study by Gomez (2002) showed that 18-month-olds listened longer to ungrammatical strings, after a three minute learning phase. Kerkhoff et.al. (2011; in press) used the same setup and added a risk group to investigate if infants with a familial risk of dyslexia are able to discriminate between the two grammars. This was done to investigate whether infants at familial risk of dyslexia show a procedural learning deficit. Infants were included in the risk group if one of the parents was dyslexic.

The results of the experiment of Kerkhoff and colleagues (in press) showed that typically developing Dutch 18-months-old infants also listened longer to ungrammatical stimuli, or in other words showed a preference to novel stimuli (novelty effect). This novelty preference demonstrated learning of non-adjacent dependencies. Thus, these results replicate the earlier findings by Gomez (2002). However, infants at familial risk of dyslexia were unable to learn these dependencies and showed a tendency to prefer the familiar stimuli (familiarity effect).

It is important to find the reason why infants with a familial risk of dyslexia cannot track these dependencies. The poor performance of infants with a familiar risk of dyslexia may be due to a developmental delay. Therefore, the first research question is;

are FR infants sensitive to non-adjacent dependencies at the age of 24 months (Experiment 1)? And secondly; do 18-month-old infants with a familial risk of dyslexia need more input to learn an artificial grammar than typically developing peers? The infants might be able to differentiate between the two different grammars after a familiarization phase of seven-and-a-half minutes (three times longer than the familiarization phase in the previous experiment of Kerkhoff et al. (in press)) (Experiment 2).

Experiment 1

Wilsenach (2006) examined Dutch children's ability to discriminate between a grammatical and an ungrammatical morpho-syntactic relation, using the Head-Turn Preference Procedure. "The perception of the past participle (which constitutes a morpho-syntactic dependency between the auxiliary *hebben* and the past participle form of the verb, namely *ge*) was highlighted in this dissertation" (e.g. 'De zon *heeft* helder *ge*schenen' v.s an ungrammatical sentence: 'De zon *kan* helder *ge*schenen') (Wilsenach, 2006, p. 165). This study showed that at the age of 19 and 25 months, at-risk infants are not sensitive to discontinuous morpho-syntactic dependencies, in contrast to 19-month-old typically developing children. A delay of at least six months in the perceptual language development is suggested in at-risk children. A possible explanation for this effect could be a smaller processing window for the at-risk children, since they are not able to detect the grammatical sentences when two syllables separated the dependent morphemes. The amount of linguistic information a person can progress is described as a processing window. An example given by Wilsenach of this processing window is: "If a child has a processing window of three words, he or she would be able to (in time) detect the dependency between the determiner and the noun in the sentence 'The dogs run'. However, this child would find it difficult to detect the dependency between the pronoun and the reflexive in the sentence 'He looks in the mirror and sees himself'" (Wilsenach, 2006, p. 78-79).

Since 18-month-old FR infants cannot discriminate between the trained and untrained sentences used in the study of Kerkhoff et al (2011; in press), this would imply that, if children are able to track the non-adjacent dependencies in the present study, the at-risk infants have developed a three-words processing window at 24 months. Based on findings by Wilsenach, one might predict that the FR infants still cannot discriminate the novel languages at 24 months. Alternatively, older infants might show better performance on this task, and behave like younger typically developing peers. In that case, we predict the at-risk infants will be able to differentiate between the trained and untrained sentences at the age of 24 months.

Methods Experiment 1

Participants

The local municipality of Utrecht provided the addresses of the parents of the participating infants, who were recruited through written requests. Infants were included with a normal birth weight, not pre- or post term, normal hearing and vision, and no known neurological problems.

13 FR infants were tested with an average age of 24 months and 23 days. One additional infant was tested but excluded because of restless behavior. As this experiment was identical to the experiment with 18-month-olds reported in Kerkhoff et al. (2011; in press), no control group was used during this experiment.

An infant is placed in the FR-group when at least one of the two parents is dyslexic. To make sure the infant is in the right group, the dyslexic parent is asked to visit the BabyLab for three short tests to confirm the reading difficulties. These tests consist of two standardised technical reading tests and a verbal competence test. The first standardised technical test is the 'Een-Minuut-Test' (EMT; Brus & Voeten, 1972). During this test the parent is asked to read a list of existing words out loud as fast and accurate possible for one minute. The researcher counts the mistakes and keeps track of time. The second standardised technical reading test is "De Klepel" (Van den Bos, Lutje Spelberg, Scheepstra & De Vries, 1994). This test resembles the EMT except for the fact that the participant reads a list of nonsense words out loud as fast and accurately as possible in the time span of two minutes. From the Dutch version of the Wechsler Adult Intelligence Scale (WAIS, Uterweijk, 2000), the verbal competence test (Analogies) is taken. In this test the parent is asked what the resemblance is between two words, for example 'Tree' and 'Fly'. The condition for an inclusion in the FR-group was a poor performance on both reading tasks, and a good performance on the verbal competence task by the parent. This is used to measure the discrepancy between verbal competence and the reading level (see Kerkhoff et.al., 2011; in press). The parents of the participating infants satisfied these criteria.

The parents of all participating infants were asked to fill out a questionnaire, in which background information was provided such as their level of education and family history of medical problems. This anamnesis is used standardly in the Utrecht University BabyLab. In addition to the anamnesis, the parents were asked to fill out the Dutch version of the MacArthur-Bates Communicative Development Inventory (N-CDI) (Zink & Lejaegere, 2002), to establish their child's receptive and productive vocabulary size. Since only six parents were able to fill in the N-CDI, these data were not analysed further.

Stimuli

The stimuli contained the same languages used in the experiment of Kerkhoff et.al. (2011; in press). Thus, there were two different artificial languages, L1 or L2, consisting of 'sentences' of three nonsense words. L1 sentences consisted of the NAD rule a-X-c and b-X-d and L2 of a-X-d and b-X-c. The X elements did not differ for both languages. The nonsense words a and c were *tep* and *lut,* the nonsense words b and d were *sot* and *jik*. The 24 X nonsense-words were *wadim, kasi, poemer, kengel, domo, loga, gopem, naspu, hiftam, dieta, vami, snigger, rogges, densim, fidang, rajee, seeta, noeba, plizet, banip, movig, sulep, nilbo,* and *wiffel.* Table 1 shows the sentences for each language, which is replicated from the study of Kerkhoff et al. (in press).

Table 1

Test strings for each training language

Language 1	Language 2
tep wadim lut	tep wadim jik
sot wadim jik	sot wadim lut
tep kasi lut	tep kasi jik
sot kasi jik	sot kasi lut
tep domo lut	tep domo jik
sot domo jik	sot domo lut

Procedure

Both the familiarization and test phase are conducted with the help of the head-turn preference procedure (see Kemler-Nelson et al., 1995). The experiment took place in a sound-attenuated booth, while the parent placed the infant on his or her lap. The parent listened to music using a headphone, to make sure was the stimuli presented to the child was masked for the parent. The experimenter observed the infant on a screen, to see whether the child was looking to the flickering lights at either side of the booth, using a button box connected to a PC to measure looking times. For the experiment, a custom-made control application was designed (running on a computer with real-time Linux) which started the trials and measured head-turn responses (see http://www.let.uu.nl/~Theo.Veenker/personal/zep/). The infant was exposed to the stimuli through loudspeakers, which were placed on either side of the infant. A green blinking light in front of the infant was used to first direct the infants' gaze to the middle of the room, and then towards one of the blinking lights above the loudspeakers. If the infant looked away from the light for more then 2 seconds, the trial was terminated and his/her gaze was directed to the middle light again and the procedure repeated itself until all trials were finished. Figure 1 shows the set up of the test booth as described in another study using the same method (Bul, 2006).

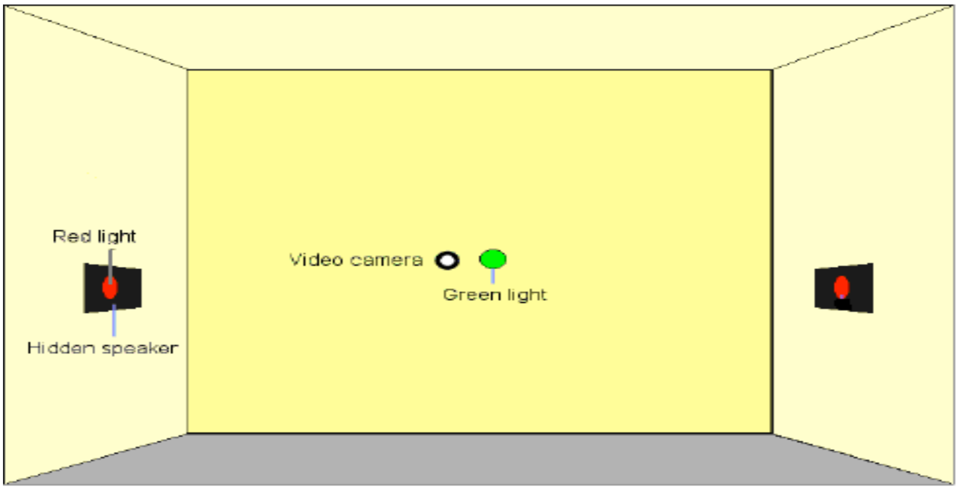

Figure 1. The test booth, with in the middle the blinking green light where the attention of the infant is directed towards. On the sides of the booth are the blinking red side lights and hidden speakers, from which the looking times are measured.

The familiarization phase in this experiment is the same as in the study of Kerkhoff et.al. (2011; in press). Thus, infants listened to one of the two languages (Language 1 or Language 2) and were familiarized with each of the 2 × 24 = 48 strings of their training language once. Learning lasted approximately 2,5 minutes (Kerkhoff et.al., 2011; in press).

After the familiarization phase, the test phase is started. The same stimuli were used as in the study of Kerkhoff et.al. (2011; in press). Thus, 8 trials, half of which came from L1 and half of which came from L2. For each infant the order of the artificial sentences was randomized (Kerkhoff et.al., 2011; in press).

Analysis

Looking/listening time data were recoded offline using PsyCode software for head-turn preference procedure data (courtesy of Judith Gervain & Luca Bonatti). Trials in which the total listening time is below 2 seconds were discarded, as an infant needed to hear at least one string to determine whether the stimulus was grammatical or not. If fewer than 2 valid trials per condition were left, the data for that child were excluded from analysis (Kerkhoff et.al., 2011; in press).

A paired samples t-test is used to compare the looking times (dependent variable) during the trained and the untrained sentences (independent variable). In addition, the same analysis is used for the group in which the restless infants were excluded.

Results Experiment 1

The means of the trained and untrained sentences are shown in table 2. The results of the paired-samples t-test showed no significant difference between the trained and untrained sentences ($t(12)= 1.23$, $p = .24$). The infants tended toward a familiarity preference, as they listened longer to the trained sentences compared to the untrained sentences.

Table 2

Means of the looking times in seconds for the trained and untrained sentences of 24-month old infants (N = 13) with a familiar risk of dyslexia

Test phase stimuli	*M*	*SD*
Trained	8.46	3.30
Untrained	7.06	3.62

It is possible attention has an effect on the looking times that is why the restlessness of the infants during familiarization was analyzed. An infant was reported as restless when he/she was moving around or fidgeting, since this behavior is assumed to be observed in infants with lower attention levels. Kerkhoff et al (in press) used the following examples of restlessness: "playing with a shoe or headset, trying to draw attention of the parent, trying to get off the parents lap, or whining". During the familiarization phase, five of thirteen (38,46%) infants were restless and eight of thirteen (61,54%) were not. To see if the restless infants influence the results, these infants were excluded from the group. The difference between trained and untrained sentences was marginally significant when the restless infants were excluded from the group ($t(7)= 2.15$, $p = .069$).

Since the FR infants are not able to track non-adjacent dependencies at an age of 24 months, it is interesting to check if this could be due to a requirement of a longer learning period. Experiment 2 examines this question with 18-month-old FR and TD infants.

Experiment 2

No previous research is known that uses an extended familiarization phase to learn non-adjacent dependencies. Evans, Saffran & Robe-Torres (2009) describe a different statistical learning task with doubled exposure. In this study, children with a Specific Language Impairment (SLI) were compared to control children in two experiments. As mentioned, there is an overlap between SLI and dyslexia (e.g. Bishop & Snowling, 2004). Evans et al. (2009) examined if the statistical word learning ability is related to the frequency of exposure. In the first experiment, the children were exposed for 21 minutes to a language in which transitional probabilities within words were higher than those between words. During the 21 minutes, the children were asked to draw a picture using a computer-coloring program. To test the statistical word learning, the children conducted a forced-choice paradigm in which they heard trisyllables (a word paired with a nonword). They were asked to choose the sound of the pair of which they recognized from before. After 21 minutes, the SLI group performed at chance, while the control group performed significantly greater than chance. In the second experiment the children were exposed to the language for 42 minutes. After this extended exposure, the SLI group's performance was also significantly greater than chance, just like the control group. This implicates that the SLI children needed more time to learn the pairs, and thus, implicit learning may improve after an extended exposure. In the present study the familiarization phase is prolonged three times compared to the familiarization phase of Kerkhoff et al. (2011; in press). Thus, the familiarization phase will have a duration of 7,5 minutes.

During the familiarization phase of studies such as Gómez (2002) and Kerkhoff (2011; in press) the infants were seated on the lap of the parent, while sitting in a test-booth. This was possible since the familiarization phase only lasted for 2,5 minutes, which was an achievable time for most children to sit still. The 7,5 minutes of the familiarization phase of this pilot is however too long for this method, thus another approach is inquired. Some examples used in other studies with extended familiarization phases are discussed.

As stated before, Evans et al. (2009) amused the children during the familiarization phase by asking them to draw a picture using a computer-coloring program. In a study of Lany & Gómez (2008) 12-month-old infants were exposed to a familiarization phase of 8 minutes and 40 seconds. During this familiarization phase, Lany & Gómez used a playroom where the infants could play with toys together with their parents. The parents were instructed not to talk during this phase, but act natural. The results showed that the obtained previous experience with adjacent dependencies (first a familiarization phase followed by a habituation phase) resulted in improved learning of nonadjacent dependencies. We adjusted the procedure of the experiment of Lany & Gómez (2008) by changes in the set-up and instructions. More details are found in the method section. If FR infants at 18 months benefit from longer exposure, they should be able to differentiate between the two languages as the result of a longer learning phase, showing the same novelty effect as the infants in Kerkhoff et al. (2011; in press).

Methods Experiment 2

Participants

The recruiting, tests for the dyslectic parents and questionnaires of the participating infants for this experiment is comparable to Experiment 1.

The control group consisted of fourteen infants (8 females, 6 males) with an average age of 18 months and 21 days. An additional twelve infants were tested but not included because of excessive fussiness or crying (n = 8) or script errors (n = 6) resulting in a faulty familiarization period. The typically developing infants came from families with no history of reading and/or language impairments.

Five infants with a familial risk (FR) of dyslexia were tested (3 females, 2 males) with an average age of 18 months and 24 days. One additional infant was tested but excluded because of excessive fussiness or crying. The FR group is incomplete, since it is hard to find participating FR infants, especially on such short notice. The mean and standard deviations of the receptive and productive vocabulary sizes measured by the N-CDI are shown in table 3. For four infants the data are missing. There is no significant difference between the two groups in receptive and productive percentile score vocabulary ($p > .1$).

Table 3

The means and standard deviations for the receptive and productive vocabulary size per group.

	Group	*M*	*SD*	*N*
Receptive Vocabulary	TD	56.1	29.3	15
	FR	74.8	18.8	6
Productive Vocabulary	TD	56.1	29.3	15
	FR	69.8	15.1	6

Stimuli

The stimuli used in this experiment are the same as in experiment 1.

Procedure

The familiarization phase started in a playroom and duration was set at 7,5 minutes. The researcher stimulated the infant to immediately start playing with the toys after entering the room. Besides the toys, a tv-screen displayed a simple screen-saver, showing a digital ‘fish tank’, without any sound at the background, to keep the infant quietly comfortable during this phase. Comparable to the procedure of Lany & Gómez (2008), the parents were instructed to talk as little as possible; only a few comforting words were allowed such as ‘yes’ and ‘no’. Also, the parent was asked to wear a stereo headphone, to mask the stimuli presented to the child. The parent sat down on a chair next to the infant, or, if the infant was uncomfortable, next to the child on the floor. Furthermore, the parent was asked to act as natural as possible with the child.

A custom-made experiment control application (running under real-time Linux on a HAL computer) ran the familiarization phase (see http://www.let.uu.nl/~Theo.Veenker/personal/zep/). The language learned in the familiarization phase was randomly assigned to the infant. Before the experiment started, some information about the child (Participant number, name, birth date, and group) was entered in the experiment program. The stimuli were presented from the loudspeakers in the room, and additionally a video recording and voice recording was created.

After the familiarization phase, child and parent were directed to the BabyLab, where the test phase of the experiment took place. During the walk to the BabyLab, the expectations of the test phase were explained to the parent. Upon entering the lab, the parent was asked to carry the child into the test booth without delay, to prevent distraction from toys present in the BabyLab.

A short training phase proceeded the test phase to accustom the infant to the situation. This training phase consisted of six sentences of the previous learned artificial language. After this very short training phase the test phase is initiated[1]. The test phase is the same as in Experiment 1.

Analysis

Looking/listening time data are recoded offline using PsyCode software for head-turn preference procedure data (courtesy of Judith Gervain & Luca Bonatti). The infant needs to hear at least one sentence to decide whether the sentence was grammatical or not. That is why trials with a total listening time below 2 seconds are excluded. There need to be at least 2 valid trials per condition, or otherwise the infant is excluded from the experiment. (Kerkhoff et.al., 2011; in press).

A paired-samples t-test with grammaticality (the looking times during trained vs. untrained strings) as dependent variables is used in the TD group. Grammatical (trained) sentences corresponded to the language learned in the familiarization phase, while non-grammatical (untrained) sentences do not correspond with the learned language.

A Pearson's chi-squared test is used to check the association between group and the longer looking times for grammatical sentences (familiarity effect). Since the group size of the FR infants only was five infants, the Fisher test is used.

[1] Six infants were excluded from the group since their training phase was longer ($N = 5$) or shorter ($N = 1$).

Results Experiment 2

This experiment is used to present an answer to the research question if 18-month old infants with a familiar risk of dyslexia need more exposure (input) to learn a grammar. Mean listening times to trained and untrained strings are presented in Table 4.

The results of the paired-samples t-test showed a marginal significant difference between the trained and untrained strings in the TD group ($t(13) = 1.85$, $p = .087$), which means the TD group had a tendency towards a familiarity effect. The FR group showed the same trend, but the group was too small for a statistical analysis. Nine out of fourteen TD infants (64%), and three out of five FR infants (60%), listened longer to the familiar (trained) sentences. A Pearson's chi-square test (with the help of the Fisher test for small group sizes) indicated no significant association between group and familiarity preference ($\chi^2(1, n = 19) = .03, p > .05$).

Table 4

Mean (sd) of looking times in seconds of trained and untrained sentences from 18-month-old infants in the FR group (N = 5) and the TD group (N = 14)

		Trained	Untrained
		M (SD)	*M (SD)*
Group	TD	8.04 (1.75)	7.95 (2.11)
	FR	8.21 (2.02)	7.86 (2.19)

Discussion

The current study was based on the results revealed by the experiment of Kerkhoff et al. (in press). These results showed that 18-month-old infants are able to track non-adjacent dependencies during a head-turn experiment. However, 18-month-old infants with a familial risk at dyslexia were not able to track these non-adjacent dependencies. The present study was used to find a reason for this occurrence. Two possibilities were examined, namely: Are infants with a familial risk delayed in the procedural memory system of the language domain? And secondly: Do infants with a familial risk of dyslexia require a longer learning phase in order to implicitly learn rule-based sequences, such as non-adjacent dependencies? To investigate those questions, two experiments were conducted. Experiment 1 examined 24-month-old FR infants with the same procedure that Kerkhoff et al. (2011; in press) used, to check for a developmental delay. Experiment 2 was aimed at investigating if 18-month-old infants with a familial risk of dyslexia and their typically developing peers, could track the non-adjacent dependencies after an extended familiarization phase.

The results of Experiment 1 revealed no significant difference between the trained and untrained sentences, unless the restless infants were excluded. After this exclusion, the infants showed marginal significant difference between the trained and untrained sentences. This implies that the FR infants did not learn the non-adjacent dependencies at an age of 24 months. Possibly, a significant effect is found on a FR-group of only relaxed infants, larger than 30. However, this is not demonstrated, and since 18-month-old infants with a familial risk of dyslexia cannot discriminate between grammatical and non-grammatical sequences either, it is suggested that these infants are at least six months delayed in their development of implicit sequence learning for the language domain. These results compare well with the results of Wilsenach (2006). Moreover, the 24-month-old FR infants showed a tendency toward a familiarity preference, with longer looking times for the grammatical sentences compared to the ungrammatical sentences. This too supports the assumption of a developmental delay in the implicit sequence learning of at least six months, since this is shown in 15-month-old TD infants (Gómez & Maye, 2005).

The ‘Procedural Deficit Hypothesis’ is supported by these results. The fact that the FR infants cannot track the non-adjacent dependencies, suggests a deficit in the procedural memory system. Moreover, the ‘PDH’ states that the procedural memory system may be involved in a language development delay, as well as in the (motor) skill learning. The problem in this experiment was the small group size. Only the data of thirteen infants were used. The FR infants were harder to find compared to the TD infants, especially on such a short notice. This experiment should be continued until the group size is comparable to the thirty-one infants tested in the study of Kerkhoff et al. (2011; in press). Also, a TD group should be tested at the age of 24 months for more exact comparisons.

The results of Experiment 2 revealed that the TD group showed a marginally significant difference between grammatical and ungrammatical test strings, but only when restless infants were excluded. This is an indication that the TD infants learned the non-adjacent dependencies. The TD group showed longer looking times during the trained sentences compared to the untrained sentences, or in other words, the TD infants showed a tendency towards a familiarity effect. The FR group was too small for statistical analysis, but showed the same trend towards a familiarity effect. Since the differences between the two group sizes are large (five infants in the FR group and fourteen infants in the TD group), and the group-sizes itself fairly small, the results of this experiment are not completely reliable. Larger groups would enable a solid statistical analysis. Each group should be enlarged to at least 25 infants. This could possibly make a significant difference in the outcome of the experiment, since the p-value of the paired samples t-test in the TD group is very close to a significant result.

A striking finding is that the TD and FR group both showed a tendency to a familiarity preference. In contrast, both Gomez (2002) and Kerkhoff et al. (2011; in press) found a novelty preference for TD 18-month-olds. Usually, a familiarization preference is reported in relatively young infants participating in complex experiments with a short familiarization phase (Hunter and Ames', 1988; Cohen, 2004; Houston-Price & Nakai, 2004). It should be expected that a non-adjacent dependency task with a prolonged familiarization phase, as used in this experiment, is easier for an infant than the task used in the study of Kerkhoff et al. (2011; in press), resulting in a novelty effect. The reasons for this assumption are that firstly, the infant is exposed to a longer learning period, and secondly, the period in which the infant is encouraged to sit still is shorter. Besides these facts, the extended familiarization phase should also predict a novelty preference, since a short familiarization phase is connected to a familiarity effect. There is no reasonable explanation for these effects based upon the previous literature. However, a larger group might show a novelty effect, especially in the TD group since these children showed this effect before. Also, the preference reversal could be connected to the experimental set-up used in this pilot (thus, the extended familiarization phase) since this is the only difference compared to the previous experiments. Perhaps the time between the familiarization phase and test phase was too long, including the waiting time for the preparations of the BabyLab by the researcher, and the walk towards the BabyLab. Normally, the familiarization phase is directly followed by the test phase. However, in a study of Gómez, Bootzin and Nadel (2006) non-adjacent dependency learning was investigated in 15-month-olds, with a pause of 4 hours between the familiarization phase and the test phase. Some infants napped between this time, and some infants stayed awake. The infants who did not nap showed learning effects, which indicate that a pause should not matter. Moreover, this had no influence on a different direction of the (in this case) familiarity effect, as found for 15-month-olds in another study (Gomez & Maye, 2005). The results for the infants who napped between the familiarization phase and test phase of the study of Gómez et al. (2006, p. 670), revealed that those infants showed a "more abstract relation, which they could apply to stimuli that were similar but not identical to those from familiarization". It would be interesting to also perform this study with the 18-month-old FR infants, to check if this has a positive effect on their NAD learning. Furthermore, it might be interesting to combine the experiments, by testing 24-month-old FR and TD infants with an extended familiarization phase.

In conclusion, the results of Experiment 1 indicated that the infants could not track the non-adjacent dependencies at an age of 24 months, which suggests a delay in the development of at least 6 months. The group-size of Experiment 1 should be enlarged to a number of at least 30 infants to make the results more reliable, and possibly a significant effect could be measured. Additionally, a TD group should be included in this Experiment to investigate the differences between the two groups at this age and the tendency towards a familiarity effect.

The results of Experiment 2 demonstrated a marginally significant effect for the TD group without poor attenders, which suggests that learning could occur if the TD group is enlarged. The effect of the FR group is not clear since this group is too small for a statistical analysis, thus there is no clear answer for the hypothesis. The experiment should be continued to obtain more reliable results. The surprising tendency towards a familiarity effect in both groups could be due to the small group-sizes, or be related to the experimental set-up.

Finally, although the statistical power is low due to the low group-sizes, the idea of Wilsenach (2006) of a delay of at least six months is plausible, as both 18- and 24-month-old FR infants may show a deficit in the procedural memory system. This is predicted by the 'Procedural Deficit Hypothesis' described above. However, the results are not strong enough to state this with any certainty.

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