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Abstract

Until recently there has been a big debate going on regarding the acquisition and learning of language in children.

The aim of the work is to study the syntactical feature of irregular verb morphology in Williams syndrome in an interdisciplinary framework. The present study has been motivated by conducting a small single case study to find out, if there is either a developmental delay in the acquisition of Williams syndrome language or rather if there is a deficit in the lexicon. Thus, it comes down to the research question:

Is irregular verb morphology selectively vulnerable in German speaking WS children?

In case this question is true, the second research question was:

Are there any over-generalization effects that occur in irregular verb inflection?

Apart from this, three tests were conducted that served as a basis for matching. The controls in the present study were matched on chronological-age, verbal mental age and an included digit span.

The results showed that German speaking WS children show a rather weak performance on irregular inflected verbs, as it has been observed by Clahsen and Almazan [7] for English speaking WS children.

In addition, we conducted a connectionist study to simulate two experimental conditions. In a connectionist network, a WS model and a normal model were implemented and trained to learn the participle and past perfect form. Additionally, the learning algorithm used was not only back propagation but an algorithm named ART (Adaptive Resonance Theory). It has the advantage that it simulates learning either very rapidly or slowly. Besides, it is biologically plausible, because of the existence of a short-term memory and a long-term memory compound.

The results suggest that the ART algorithm is better suitable for modelling irregular verb inflection in a normal model, whereas back propagation simulates better a delay in irregular verb

acquisition. In conclusion to that, computational modelling, such as back propagation and ART algorithm give a perfect opportunity to simulate developmental disorders and normal development of language depending on the given framework.

Key words: Williams Syndrome, verb morphology, irregular verb inflection, experimental, connectionist modelling, neural networks, learning algorithms, adaptive resonance theory, back-propagation.

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List of Abbreviations

WS Williams Syndrome

DS Down Syndrome

STM short-term memory

LTM long-term memory

WM working memory

TD typically developing

PPS peripheral pulmonic stenosis

NM Normal Model

WSM Williams Syndrome Model

1. Introduction

Williams syndrome is a rare genetic disorder that has a prevalence of 1:7500 [1]. It has been claimed that there are “dissociations” within WS. It is better viewed from the perspective that there are some strengths and weaknesses concerning several cognitive abilities.

For example language in WS children is developing very slowly during the first years of their language acquisition. Although by their school age they catch up on the deficit, having acquired considerable fluent speech and grammatical abilities in comparison to their cognitive restrictions. The dissociation occurs between considerable well language abilities in contrast to poor mathematical reasoning abilities.

Another dissociation occurs within their auditive short-term memory that is spared compared to the Visio-spatial and long-term memory that is impaired.

Based on this background it is interesting to study irregular verb morphology in WS, because there is a deviant development compared to TD controls. Namely, that WS children perform poor with irregular verb stems, while they can inflect regular verb stems as well as younger TD control children [7].

Added to that, studying malfunctions tells us more about a certain cognitive ability. The number of cognitive restrictions and the contrastingly good functioning linguistic abilities give an indication that language is organized in another way than in typically developing (TD) children [3]. In recent years WS became important for cognitive psychologists as well as neuroscientists and computational linguists. What they all have in common is one guiding question: How is the cognitive architecture organized that at least parts of language are preserved?

1.1. Theoretical background

A big controversy in WS concerns, whether or not a dissociation between language and other cognitive skills exists. Bellugi et al. [4] reported that language skills are relatively “spared” in WS, meaning that “they are significant better in relation to other cognitive abilities.” Within the language skills she observed some aspects in language, such as morphology and syntax, where WS children show a great strength. Although, there are still unresolved fields concerning the intactness of the language level in WS.

One crucial paradigm is the modularity of language, meaning there is a separate module responsible for language and another module responsible for other cognitive abilities. One, who argues in favour of this theory is Fodor, who claims that: „A cognitive function is modular in the strong sense, if it shows informational encapsulation, processing only a subset of the information represented by the organism.” [11]

A neurocognitive developmental view is favoured by Karmiloff-Smith. She argues that for the study of genetically based developmental disorders, such as WS, atypically developing children don't have a normal brain with parts intact and parts impaired, but brains develop differently through embryogenesis. For example, language as well as other functions, such as mathematical ability she claims that it can be seen as an ability that develops through a developmental trajectory. According to Karmiloff-Smith modules are a result of a process of modularization [25].

Another issue in Williams syndrome (WS) research explores, whether the inflectional system is affected by a selective deficit as claimed by Clahsen and Almazan [7] for English WS children. Clahsen's approach is based on a Minimalist Morphology in order to explain regular and irregular inflection. According to Clahsen's approach regular verb inflection builds upon a default rule, meaning that *-ed* is attached to a verb in English language. While in irregular inflection verbs, such as *go – went – gone* are stored as whole in the lexicon and are accessed via sub nodes of lexical entries. The deficit of WS children in irregular words results in an inability to access these sub nodes [5].

A contradicting view is taken according to Thomas et al. [6], who argues that WS is caused by a delay in language development. He claims that language learning is based on a connectionist way of learning. Therefore he examined the past-tense production in group of 18 WS individuals by controlling chronological age and found an age disparity in irregular verb performance.

Within the debate, the ability of WS of inflecting verbs and nouns was taken in account. According to Clahsen and Almazan [7], who conducted studies on English participle and noun plural inflection there is a difference between regular and irregular morphology in English WS children. They discovered a rather poor performance on irregular verbs and an overgeneralization of the regular suffix. On the other hand WS children inflected regular verbs at the same level as younger unimpaired controls. This gives an indication to a clear dissociation of language regarding the inflection system.

On the other hand Penke, M. & Krause, M. agreed on the results of Clahsen and Almazan in their own study of inflection of irregular verbs. They observed two individuals with WS, where WS and control subjects didn't differ in overall performance rates [8].

One of the research questions in this thesis, following the argument of Harald Clahsen was, if WS individuals are selectively vulnerable to irregular verb inflection.

However, hypothesis building is based on a German study from Penke, M. & Krause, M. who tested German past tense production in WS. Additionally it is motivated by the argument of Clahsen that “the computational, rule-based system for language is selectively spared, while lexical representations and/or their access procedures are impaired.” [107]

The second question of interest is, if the results show a pattern of impairment, as shown in previous studies by Clahsen or Penke, M. & Krause M. the following question is, if over-generalization takes place. Over-generalization means the usage of the regular verb postfix *-te* in German instead of the correct inflected form, such as in: *gehen - gehte - gegangen*.

The third research question concerns computational modelling and examines, whether the learning algorithm for back propagation can be substituted by using an adapted form of the ART (Adaptive Resonance Theory) algorithm. The underlying hypothesis was that the ART algorithm is better suitable for simulating language development of inflected verbs in TD language.

Finally, the dissociation between short-term memory and long-term memory is investigated, based on testings conducted in the framework of this thesis. The results of the short-term memory tests, such as the digit-span and the Mottier test are evaluated in relation to the working memory model of Baddeley and Hitch [30].

1.2 German Inflection of regular and irregular verbs

The classification of verb inflections is taken from Wunderlich [9] for German language, who claims that irregular inflected participle forms, such as *(ge)trunken* are stored in structured lexical entries that are derived from a base node. Added to that, Wunderlich claims that *-t* ending in regular inflection is generated by default. It is the consequence of a rule that applies *-t*, when there is no strong form in memory. The *-t* ending is used by German speakers to inflect low-frequency verbs, as for example in *bleichen – bleichte – gebleicht*.

The German verb system has three morphological classes: weak, strong and mixed verbs. Examples for each of the groups are given below:
German participles consist of the prefix *ge-*, a verb stem in the middle and the endings *-t* and *-n*.

Infinitive Preterite Participle

(1) *Kaufen – kaufte – gekauft*

(2) *Hinken – hinkte – gehinkt*

(3) *Gehen – ging – gegangen*

(4) *Trinken – trank – getrunken*

Regular verbs, such as (1&2) don't show stem changes in the participle form and have the suffix *-t*. Thus, the participle form is predictable. Irregular forms, such as (3&4) show a modification of the stem vowel and have the participle ending *-n*. It is not possible to determine, whether the verb is regular or irregular by looking only at the stem vowel or the phonological shape of the verb stem, as can be seen by comparing (2) and (4).

Apart from this verb inflection was also studied by Marcus et al. [78] by the comparison of regular and irregular inflection in German and English. In their study they found out that the German participle *-t* applies to a much smaller percentage of verbs than its English counterpart *-ed*. But the affix behaves similar as the English counterpart, namely as a default ending.

Inflectional rules, such as the default ending was investigated by H. Clahsen and M. Rothweiler in 1993, where they reported that children systematically apply *-t* and not *-n*, which speaks for a default participle generation rule [19]. The phenomenon that occurs is called over-regularization..

To test participle forms regular and irregular sentences Penke and Krause [8] used a simple sentence completion task. The sentences are presented on cards, where each subject can be tested individually.

Ich ging. *,I went'*

Ich bin _____. *,I am going'*

Ich spielte. *,I played'*

Ich habe _____. *,I have been playing'*

In the sentence completion task they elicited about 100 regular and irregular noun plurals that served as fillers. To ensure that the test items of each stimulus are evenly distributed a pseudo-random order in the groups tested can be used. The formation and elicitation of noun plurals are described in the next paragraph.

Regular and irregular inflection in German noun plurals

The German plural system consist of five different plural markers: *-(en)*, *-s*, *-e*, *-er* and zero [0].

(1)*Auto – Autos –s*

(2)*Blume – Blumen –n*

(3)*Tisch – Tische –e*

(4)*Kind – Kinder –er*

(5) *Ritter – Ritter*

The *-s* plural serves a special role in the plural system, as it is a default plural that can be called productive. It means that it is free in its distribution and is only blocked by a few sibilants. Also it occurs with nouns of any gender. All the other plural forms are used in a distinct context. For example, if they are subject of a phonological constraint:

Most words of German end with a schwa ending (*-e, -el, -en, or -er*) or with one of the other endings, such as *-ung* (f), *-heit* (f), *-keit* (f), *-schaft* (f), *-in* (f), *-nis* (n or f), *-tum* (n, seldom m), *-sal* (n or f), *-lein* (n), *-chen*, *-ling* (m), or *-ig* (m).

According to an analysis of Wunderlich [16] there has been developed a theoretical overview of the different plural markers.

The *-n* plural for Hemd (- Hemden) is called *-n-fem* plural whereas the *-n* plural for Blume is called **non-n-fem** plural. The German non plural is elicited within a sentence completion task. The noun phrases were given like the example below:

(1) *Kind*

(2) _____ ,*Kinder*'

20 plural forms were elicited for each different plural marker, which results in 100 different plural nouns per subject.

To control for frequency effects the items were closely matched for frequency between

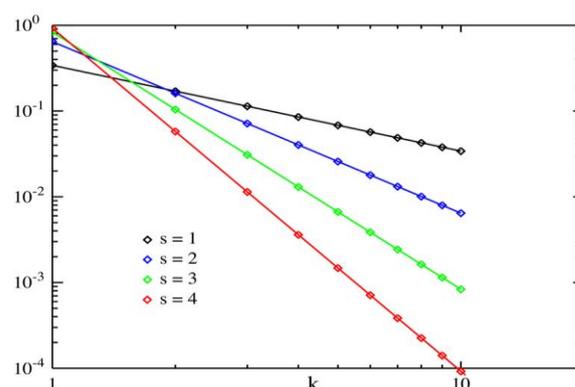


Figure 1 Zipf's Law

and within each group. Frequency effects can be described according to the linguist George Kinsley Zipf, who proposed the so-called Zipf's law. It states that given a corpus of utterances the frequency of any word is inversely proportional to its rank in the frequency table. In short the most frequent word in a corpus will be about twice as frequent as the second most frequent [20].

2. Description of Williams Syndrome

2.1. Clinical description of Williams Syndrome

Williams Syndrome is characterized by a wide range of symptoms that occur in different frequencies in their expression. Therefore there will be represented a short listing of the main clinical symptoms and a complete overview in a frequency table.

Common observed symptoms are cardiovascular, such as peripheral pulmonic stenosis (PPS) and aortic stenosis (SVAS), musculo-skeletal, such as lordosis and other orthopaedic manifestations, cranial-facial, such as the characteristic “elfin” face, otorhinolaryngologist, such as hoarse voice and a prevalence for hyperacusis, gastrointestinal, such as hypercalcemia, ophtalmologic, such as hyperopia and strabismus and genitourinary symptoms such as pulmonary stenosis and renal artery stenosis.

Apart from the clinical symptoms, the abilities in WS are expressed quite differently depending on their phenotype manifestation. The next section describes the abilities of WS in relation to their linguistic behavior. At first the chapter represents the behavioral phenotype of WS resulting the clinical manifestations.

2.2.. Cognitive and Behavioral Phenotype

Williams syndrome is characterized by a different development of a number of abilities resulting in the expression of several clinical manifestations that are described in the following. Added to that, there are represented a number of tests that determine the relation of language and cognition.

Cognitive abilities

WS has a distinct cognitive phenotype that ranges from severe to mild mental retardation, in 75% of individuals with WS. The measured IQ, according to Bartke and Siegmüller differs between 40 and 90 [21]. The cognitive profile was described by Bellugi et al. [4] as asynchronous performance pattern on different cognitive domain levels.

Academically, individuals with WS perform relatively well in reading. Adults may even read at the high school level. Thus, the range of achievement is wide. Reading skills correlate with cognitive ability rather than language-related skills [22]. Difficulty with writing, drawing, and mathematics is significant.

Social abilities

The social abilities were first described by Bellugi et al. [24]. They found that WS children are extremely talkative and friendly. This behavior goes together with over friendliness beyond the level of normal [23].

Visio-spatial abilities

Visio-spatial construction and visual cognition is described as a weakness in WS children. This has been tested by a number of people. One of the first studies showing this deficit was the drawing test done by Bihrlé et al [24].

Face Processing is an area of strength in WS, that was detected to be abnormal developed by Deruelle et al. [25]. In her studies Karmiloff-Smith [26] concluded that there is a local processing bias for the face processing task.

Numeric abilities

In general Zukowski [27] discovered that WS children have a greater deficit in arithmetic and in their numerical abilities. Bellugi et al. [4] also found out that WS children experience severe problems in the handling of money. The Wechsler Intelligence scale (WISC-III UK) test was used by Howlin et al. [28], who found out, that arithmetic skills are at low level together with reading, spelling and social adaptation.

The subject of arithmetic and mathematical abilities will be examined in more detail in chapter 5 of the thesis.

Musical abilities

WS children are highly sensitive to music, due to the hyperacusis, which is a sensitivity to a certain frequency. They seem to be drawn towards music, even though they are sensitive to loud music and noise. In fact, WS children stay more focused during music playing. Among WS

children that are sensitive towards noise and music there are also some, who are gifted in music [29].

2.3. Determining relations between language & cognition

For determining relations between language and cognition a number of tests are used: The tests listed are recommended as a standard in “Languages across Williams Syndrome” Not all of them are used during the empirical study conducted. They will be listed here to get an overview. [105]

First, DAS (Differential Ability Scales) measures the intellectual functioning, containing

- a verbal cluster measuring the ability to define words and perform verbal reasoning tasks,
- a non-verbal cluster measuring the sequential abilities, and
- a cluster measuring spatial reasoning and memory.

Furthermore, it contains pattern construction and recall of digits. Visio-spatial construction is described as a weakness in WS children with a mean standard score of 54. Also pattern recognition is measured with a mean standard score of 23,25 at the low end.

Second, the Kaufmann Brief Intelligence Test (K-BIT) is used in combination with the DAS and measures for verbal ability and non-verbal reasoning ability. In K-BIT the IQ is composed of verbal and non-verbal measures, where non-verbal IQ with a standard mean score of 68,52 is lower than the verbal IQ of 71,77.

Third, the Mullen Scales for Early Learning is used, as a scale measure for toddlers and pre-scholars containing:

- a Visio-spatial subtest,
- two language subtests and
- a visual reception subtest.

The test shows that a pattern is already present at an early age of two. In this test WS children score lowest in the fine motor test with a standard mean score of 21,65 normally in a range from 20 to 31. The mean standard score for receptive language is 30,47, whereas for expressive language it is 30,47.

Fourth, the Peabody Picture Vocabulary Test (3rd edition) tests single word vocabulary knowledge. It is combined with the Expressive Vocabulary test, measuring expressive single word vocabulary. In the PPVT-III Test the mean standard score was 77,91 in a normal range from 40 to 120.

Finally, the Test for reception of Grammar (TROG) measures the receptive understanding of grammar. Subjects have to perform naming and sentence repetition tasks. The purpose of the test is to distinguish different types of comprehension failures. There is also an assessment of grammaticality judgement, anaphora interpretation and pragmatic cues in word learning that is taken in account to make an overall linguistic profile.

TROG measures the receptive understanding of grammar. Sentence construction ranges from single words to simple sentences such as: "They are sitting on the table". The mean standard was 73,67 with a normal range of 55 to 112. The test is available and has been conducted in a version for German speaking children (TROG-D) after it has been adapted by A.V. Fox.

2.4. Acquisition of Language in Williams syndrome

Regarding the linguistic profile of Williams Syndrome we distinguish between the following parts: lexical & semantic features and syntactic features. The system of pragmatics is described in addition for the reason of completeness. The description of these abilities in language development is important to build an overall profile.

2.4.1. Development of lexical and semantic features

Lexical or vocabulary acquisition is a complex task requiring

- the representation of the sound patterns of words,
- the building of concepts for objects, and
- the mapping of a sound pattern for a novel word to a particular concept.

Typically developing children master word comprehension by the onset of 10 months and word production by 12 months of age [78]. However, in Williams syndrome vocabulary acquisition is delayed up to 12 months [80].

When examining the vocabularies of WS more precisely some inconsistencies are shown, pointing out a semantic organization that is different from TD controls.

For example, when WS children are asked to give a description of something, they frequently use uncommon words in their language. Bellugi et al. pointed out in 2000 that in day to day conversation with WS individuals they use rather sophisticated words that are not expected given their cognitive functioning. Although, words are often used correctly, they are mostly not used in their appropriate context [4].

Several studies have been conducted to investigate the occurrence of unusual words within WS. The mentioned studies are meant to serve as an overview and are not well established findings.

For instance, semantic fluency tasks are used to examine the organization of the mental lexicon and measure the extent to which names can be accessed automatically. For example, WS subjects are asked to name as many examples of a semantic category as possible. WS individuals behaved rather differently from Down Syndrome (DS) individuals. They produced a larger num-

ber of words even in correspondence with their chronological age, whereas DS individuals had a higher frequency for repetitions [99].

Furthermore, children with WS start naming objects before they start to point at them. There have been found some developmental trends in the naming abilities of WS. The nature of semantic organization was examined in a study from Rossen et al., where they investigated the processing of homonyms within WS. In a free association task, they had to say the first word that came to their mind after hearing the homonym. WS individuals performed similar than normal controls and mostly responded with words that were primarily associated with the given homonym. Apart from that, a similarity judgment task and a definition task were carried out. The results showed that WS individuals were as likely as controls to give definitions for the primary meaning of homonyms [92].

The experiments show a sensitivity for frequency in their vocabulary as it has been shown by Lukacs, Racsmany and Pleh in 2001. They observed in a study involving Hungarian subjects that a higher working memory span indicates a larger vocabulary size. The effect was less obvious for frequent words, but especially could be seen in the case of infrequent words. It was shown that children with a higher working memory span learn less frequent words more easily. The effect in WS subjects producing unusual words without knowing their meaning is explained by the fact that they simply store the phonological string [30].

2.4.2. Development of syntactic features

According to Bellugi and Wang in 1996 it is claimed that “Williams Syndrome Subjects exhibit spontaneous language that is not only syntactically impeccable, but also grammatically complex across a wide range of structures” [4].

In contrast to their cognitive impairment WS individuals use sentences with complex syntax [82]. To assess their comprehension and use of complex syntax, several studies were conducted. The ability to detect anomalies in the syntax of a sentence depends on the knowledge of syntactic constraints and the ability to reflect upon grammatical structure. These meta-linguistic abilities are in general mastered after the acquisition of grammar in typically developing children.

Moreover, in language production of adolescent and adults with WS, it can be seen that they produce a variety of grammatically complex structures, such as passive sentences, conditional clauses and embedded relative clauses.

For example, in a sentence comprehension task using conditional questions adults with WS respond in complete sentences, indicating that they understand the question and more importantly respond with the appropriate grammatical marking. For sentences like: ‘What if you were a bird?,’ responses were given:”I would fly through the air and soar like an airplane and dive through trees like a bird and land like a bird,”.

Apart from that, on several syntax tests, WS individuals scored significantly higher than individuals with DS, including the Test for Reception of Grammar (TROG; Bishop,1982) that was used in this thesis.

On the one hand, WS subjects show relative strong abilities in recognizing different structures and passives. On the other hand, they seem to have problems with neither-nor structures and sentences with relative clauses as shown by Karmillof-Smith et al [102].

Also, it has been observed by Singer-Harris, Bellugi, Jones & Rosson [15] that there are contradicting patterns of language acquisition in Williams Syndrome and Down Syndrome children. For example, WS children show a strong development of grammatical structures, whereas DS shown an advantage for communicative gestures. Both populations have in common that they are delayed regarding their cognitive abilities.

There is a debate going on, whether using DS individuals as controls leads to a distorted view of the syntactical abilities of WS individuals [99].

The reason is that DS subjects show special difficulties with morphology and complex syntax and therefore grammatical abilities of WS individuals seem in contrast especially spared. A comparison of grammatical abilities of WS to TD children matched on verbal age would be more useful [10].

Moreover, syntactic competence in WS differs from that of typically-developing children in qualitative terms. This has been pointed out in a study on Italian subjects by Vicari et al. in 2001, where a lot of errors made from WS resulted from over-generalizations [103].

However, a rather strong tendency for over-generalization of regular forms was found for English speaking children with Williams Syndrome by Clahsen and Almazan. They examined

regular and irregular past tense formation in WS and found that WS subjects experienced no difficulties in producing the past tense of novel and existing verbs, although there is “a marked dissociation between regular and irregular inflection in WS”, meaning that regular affixes are more frequently used.

That's why indications are given for a dissociation between unimpaired regular and an impairment of the irregular morphology. This has also been seen for other languages than English such as in study conducted by Lukács et al., where she investigated regular and irregular suffixation of accusative and plural forms and observed “the usual superiority of regulars over irregulars” [30].

2.4.3 Development of the pragmatics system

Concerning the development of pragmatics there have been conducted a number of tests in order to measure pragmatic ability. For example, storytelling has been tested by Bellugi et al. by means of “The Cookie Theft” picture that involves testing pragmatics. The study showed that stories told by Williams children were longer than in age matched children. Although, they had the common feature that WS subjects used linguistic devices, such as sound effects, stress markers and referring to mental states a lot more frequently to get the listener's attention [16].

Based on the fact that WS subjects take utterances literally, as well as they don't understand jokes and double sense, a study was conducted by Sotillo and colleagues [31]. He tested the ability of metaphor reasoning in a task where WS people were given a matrix to choose one out of four pictures that matched in the matrix most.

For example: A great bird, makes a loud buzz, it has wings without feathers and has its nest on the ground. What is it? The right solution would be an airplane.

The task was to chose among 4 pictures the one with the metaphorical meaning, whereby two pictures were connected with the literal meaning. The result of the study showed that WS people have difficulty in understanding figurative language, meaning that they don't understand analogies.

3. Study 1: Language

3.1. Introduction

In the framework of this thesis a small empirical study was carried out to investigate irregular verb flexion and the role of phonological short-term memory, as a key element in language processing. The experimental design was related to a test done from Penke M. & Krause M. to test regular and irregular inflection of verbs in German language [8]. Additionally, we developed a design for testing the controls, which varied from the original study.

Due to the number of subjects participating in the study the thesis lacks the requirements for a methodologically valid study as two subjects are a small sample size. Therefore the analysis is rather of qualitative nature than quantitative. Thus, the present work can be viewed as a case study using different controls for matching.

3.2. Subjects

During the course of the study, two subjects with Williams Syndrome aged between 17 and 18 participated in the study. The names of the subjects have been changed to preserve their anonymity.

Sandra was aged 17;10 at the time of testing and is living currently in a adults home for disabled people needing extra help. She has several symptoms that are characteristic for WS, such as an elfin looking face, strabismus and hypertonia. An IQ Test, HAWIK-R (Tewes, 1983), was conducted by Prof. Schanner-Wolles. The test showed an IQ of 46 points that was determined with a verbal IQ of 53 points and a performance IQ of 51 points. In her education she was enrolled in a class with children for severe mental retardation. She has a open minded and friendly personality, indicating an interest at everything new going on. For example, she showed great interest in the mobile phone with which the linguistic tests were recorded, because she wanted to listen to her own voice. Her mother pointed out that is sometimes extremely naive opening the door to people that are absolute strangers. Furthermore, regarding her language background she has been taken to Hungary by her Hungarian nanny before the age of 6. Resulting this she spoke little

German when entering the children's home in Vienna again. Today she is not able to produce Hungarian words anymore and her German is very fluent at the present point.

Martin was aged 17;01 months at the age of testing. He shows characteristic symptoms of WS, such as the “elfin” looking face. Furthermore, dental problems such as malocclusion, have been reported as well as decreased feeding and irritability during early childhood. Apart from that, he showed a delayed onset of language acquisition, although the exact delay can't be determined, because it was not measured at that time. Up to now, Martin has acquired considerable reading and writing skills, though he writes very slowly for his age, which might be due to the motor problems related to WS. In contrast to Sandra, he has acquired the basic arithmetic operations such as addition, subtraction, multiplication and division in addition. In general, Martin has troubles on doing more than one thing at the time in combinatorial tasks. Moreover, he shows the extreme friendliness and social intervening that is reported with WS subjects. There were no previous intelligence tests carried out, which is why an exact IQ can't be determined in the frame of this work. Although, by means of clinical assessment it was found out that he is mildly mentally retarded. Therefore, he was enrolled in special school for children having a handicaps in learning and needing further assistance.

3.3.Methods

In general, the methodology in this study consisted of administering 3 tests. These were the TROG-D (D. Bishop 1983) to test the reception of grammar in German WS subjects, the Mottier test to determine the phonological memory and the Picture Peabody Vocabulary Test III (PPVT, Dunn and Dunn 1981) to assess verbal or lexical age.

3.3.1 Methods – Mottier Test

First, the Mottier test was conducted. The subject was instructed to repeat artificially constructed nonsense words. The test started with 2 syllables and went up to 6 syllable words, as it can be seen in illustration 6. Before starting the WS subject was instructed to reproduce the exact artificial constructed words and not reproduce words that are known from previous experience.

Apart from that, the interviewer that conducted the test was sitting near the subject, but wasn't

2-Silber	3-Silber	4-Silber	5-Silber	6-Silber
rela _____	kapeto _____	pikatura _____	katopinafe _____	pekatorisema _____
noma _____	giboda _____	gabodila _____	gebidafino _____	dagobilaseta _____
godu _____	lorema _____	monalura _____	ronamelita _____	leraminofeko _____
mera _____	tokipa _____	topakimu _____	tapikusawe _____	kapotilafesa _____
luri _____	dugabe _____	debagusi _____	degobesaro _____	bigadonafera _____
limo _____	nomari _____	relomano _____	muralenoka _____	nomalirakosa _____
___/6	___/6	___/6	___/6	___/6

Figure 3: Mottier Test Layout

looking at the subject directly in order to prevent lip reading.

There exist various test norms, distinguishing between class norms and age norms. For the possibility of comparison, there should be taken in account rather the age norm, if matched on mental age or chronological age.

Before conducting the Mottier test the previously mentioned IQ test, HAWIK – R (Tewes, 1983) was performed in order to assess the intelligence quotient.

HAWIK-R is an intelligence test that has specific subtests for verbal intelligence and general knowledge. It is used for diagnostic examination in single case studies. For example, some of the tasks that are tested are repeating of digits, reasoning in calculation, picture sorting and completion.

3.3.2 Methods – Picture Peabody Vocabulary Test

The Picture Peabody Vocabulary Test III (PPVT, Dunn and Dunn 1981) is an intelligence test that is used to assess verbal memory and lexical age by presenting four pictures. In this set of four pictures only one of the four is correct. The test can be administered easy and gives a quick estimate of the subjects verbal ability. It can be used for subjects ranging from 2 and a half up to 90 years of age. The subject doesn't need to read or write the items. Instead the task is to point at the correct answer.

Repeats of the items in a task are allowed, however the testing is stopped, if the subject fails to recognize 5 items in a row.

Moreover, the total score achieved can be converted to a percentile rank or a standard deviation score and correlates with the score of the Wechsler intelligence scale WISC 3. The words were translated from Hungarian to German, because the test was applied in German language.

3.3.3 Methods – TROG-D

The TROG-D is used for assessing the reception of grammar and has been adapted from TROG (D. Bishop, 1983). The adapted version of TROG-D offers a testing procedure for children aged between 1;0 to 10;11¹.

TROG-D doesn't require the production of language. Added to that the repetition of test items is allowed as well.

Each grammatical construction is tested on four items to avoid guessing the correct answer.

There are distractors in every task that indicate, if there has been made a lexical or grammatical error. Thus, in each task there are lexical and grammar distractors

1 The notation shows years and months after the semicolon

3.4. Results

3.4.1 Results – Mottier test

The result shows that Sandra has a raw value of 8 from 30 correct answers. According to class norm B in Figure 4 the value is interpreted like that; With a minimum of 9 correct answers the subject falls into class 2 and has a percent rank of 1-5%.

Klassenormierung B (Handbuch zum Kieler Leseaufbau)

Klasse	Prozentrang				
	1-5	25	50	75	100
2	9	21	23	27	30
3	9	19	21	26	30
4	20	23	24	28	29
5	17	24	26	28	30

Figure 4 Class Norm B

Sandra performed well with 2 syllables (4/6), medium with 3 syllables (3/6), but had great difficulties with 4 (1/6), 5 (0/6) and 6 (0/6) syllables.

Apart from this, she switched vocals, consonants and syllables. There was an occurrence of wrong naming of vocals and consonants. Moreover, Sandra omits certain vowels and consonants.

There occurred a number of articulatory distinctions. Sandra tried to produce known words although she was instructed to repeat artificial words. In the production of the artificial words she showed an affinity to names. Added to that, she had considerable difficulties in distinguishing hard and soft consonants such as *t* and *d*. This indicated, that she had difficulties in recognizing them during speech.

Apart from being nervous in the beginning, Sandra was motivated to solve the given task at her best performance. Moreover, she recognized when she produced errors, without being told so. Based on the low raw value, the test was repeated after two weeks, in order to see if nervousness has been a reason for the result.

In the second trial the subject performed even at lower scale. She achieved a raw value of 3 correct answers from 30 items. According to the class norm B (Figure 4) she performed lower than class two. The percentage was not calculated at this point. She had three correct answers in the first class of 2 syllable words. All higher syllable words in the second trial were wrong.

An analysis of the errors made, showed a similar pattern as in the first test. She switched vocals, consonants and syllables. Furthermore, there was wrong naming of vocals and consonants, such as in kapotila (correct: gabodila) and pikatusi (correct: debugusi). Apart from that, she frequently omits letters, such as oma (correct: roma) and pikasowe (correct: tapikusawe).

Martin's raw score was 10 correct answers from 30 items, showing difficulties in 4 syllables, but performing well with most of the 3 syllables. He performed well with 2 syllables (5/6) medium with 3 syllables (4/6), but he had great difficulties with 4 (1/6), 5 (0/6) and 6 (0/6) syllables.

His main errors made were that he switched vocals and omitted them in words longer than 3 syllables. Added to that, there were no further articulatory distinctions noted. Martin was instructed just as Sandra not to reproduce known words, although that didn't seem any problem.

The same analysis of the errors as previously, showed a similar pattern than in Sandra's testing. He switched vocals and syllables. Furthermore, he showed wrong naming of vocals and omitted letters, such as bagusi (correct: debugusi).

Apart from that, he recognized errors made by himself. In general, the overall error rate is lower than in Sandra's testing.

3.4.2 Results – PPVT

The test was first conducted with Sandra, who performed in the upper range and had a total score of 79 correct items of 100 items. In total, this is a percentage of 21% of incorrect answers. Within the 21% of incorrect answers 11 items were corrected by her immediately after she made the error. The duration of the test took 20 minutes with an average answering time of 20 seconds.

Martin performed slightly better with a total score of 88 correct of 100 items, indicating that he had no trouble in recognizing the correct items. Following, he had a percentage of 12% of incorrect answers. His testing average on one task was 10 seconds.

3.4.3 Results – TROG-D

Sandra had a raw value of 9 correct groups from 23 groups in total. In total, she has 61 correct answers and 22 incorrect answers, which were mainly due to the grammatical distractor element.

The table below shows her individual results on each of the subgroups.

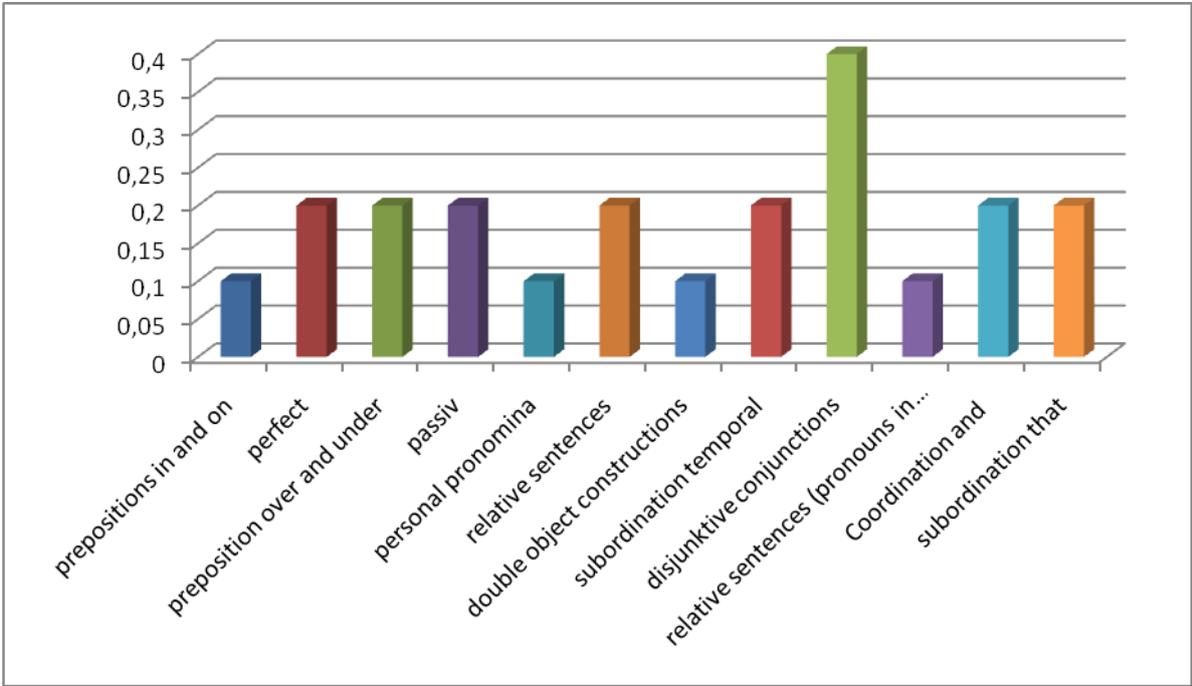


Figure 5 Results of the subgroups in TROG-D for Sandra

Martin had a raw value of 13 correct groups from 23 groups in total. In total, he had 68 correct answers and 15 incorrect answers, which were caused by different distractor elements.

The table below shows his individual results on each of the subgroups.

Figure 6 Results of the subgroups in TROG-D for Martin

3.5 Testing the controls

The controls were matched with the PPVT test, the Mottier test and TROG-D. The challenge was to the verbal age, the phonological memory age and the chronologically age of the WS children.

Controls	PPVT III	Mottier	TROG-D
C1	X		
C2		x	
C3			x

The table above shows how the controls were matched. C1-C3 reflects the control children that were chose to determine the equivalent age of the WS individuals. It means that we have to find a control child 2 (C2) for instance that performs in the same way as Sandra to determine the lexical age of Sandra. The Mottier test was used to determine the phonological short term memory age, whereas TROG-D aimed to figure out, if the reception of grammar was intact.

The results of the control testing can be seen in the following table below. It can be interpreted that in the Mottiertest most of the control children fell within the percentile range of 75 to 100 percent reflecting a typical development. For the Mottiertest none of the children could be matched with Sandra's or Martin's results.

Concerning the TROG-D, the raw value that matched Sandra's testing was from control child Lydia aged 7;3, Therefore, Sandra's is chronological age matched to a child at the age of 7 years and 3 months.

On the other hand, Martin's TROG-D result could be matched best with Adams result indicating a raw value of 13. His chronological age therefore can be set to 10;1.

When comparing the PPVT results with the testing of the controls there was no big difference shown. Either Sandra's and Martin's results were in line with the results from TD children.

A	B	C	D	E	F
Mottiertest			TROG - D		
	Age	Digit Span raw value	raw value	Percentage	T value
Marita	10;4	27	19	72	56
Peter	10;3	26	15	16	40
Markus	11;0	25	20	90	63
Lukas	8;6	24	18	83	59
Selma	9;3	25	16	33	46
Martin	8;11	22	13	18	41
Birtalan	9;2	26	17	46	49
Michael	8;1	25	15	38	49
Lydia	7;3	24	10	8	
Adam	10;1	27	13	5	34
Benni	10;0	25	12	1	28
Elzhara	11;7	28	17	34	46
Hager	11;9	29	19	72	56

Figure 7 Results of the controls testings for TROG-D and the Mottier test

4. Study 2: Language

4.1. Introduction

The second study on language was motivated by first the research question and asked, whether there are any overgeneralization effects that occur in irregular verb inflection?

It is interesting to look at the frequency, because there have been made different observations. While Thomas et al. observed within irregular existing verbs WS children perform better with low frequent existing irregular words, than with high frequent existing irregular verbs [109], Lukacs et al. couldn't find a differing performance of WS between frequent and infrequent items, therefore the finding was a lack of frequency in the WS group [30].

4.2. Methods

4.2.1. Methods – Bielefelder test

In order to address the question formulated there was adapted a test from the university of Bielefeld [110]. The test was developed mainly for the assessment of people with aphasia. It was adapted for this study in order to test the ability of WS children to inflect irregular artificial verbs in a context.

For example a task was:

(1) *'The men were **wimming** in the Ponz.'*

The task for the WS subject was to elicit the correct perfect and preterite form.

The preterite form was elicited in the following way:

(3) *'Yesterday the men [wim] in the pons'*

The correct expected inflection would be:

(4) *'Yesterday the men **wam** in the pons'*

The test was carried out with irregular pseudo verbs and regular existing verbs.

4.2.2 Methods – Action word test for irregulars

In addition to the pseudo word test from the university of Bielefeld there was applied another test for irregular verbs. This test was adapted from Penke M. & Krause M. and contained simple construction like:

Examples (irregular Verbs)

High frequent:

(1) *werfen* - ____ - *ge*

(2) *werfen* - *warf* - *geworfen*



Low frequent:

(3) *heben* - _____ - *ge*

(4) *heben* - *hebte* - *gehoben*



As shown in the example for the low frequent verbs the subject made an overgeneralization error. The correct elicited form would be: *heben – hob – gehoben*.

Subjects were asked to figure out the correct perfect and preterite form. The test takes in account spoken frequency counts based on the CELEEX corpus.

4.3 Results

4.3.1 Results – Bielefelder test

Sandra had enormous difficulties in understanding the sentences. She had a raw score of correct items. Her performance with irregulars was very poor as she had correct for the irregular pseudowords.

Commonly made errors were such as:

(1) *Jesus hat am Kreuz gefeiden.*

The correct form would be: gefitten

(2) *Das Bild ist über dem Bett geschängt.*

The correct expected form would be: geschangen. The error made is a typical overgeneralization.

Martin understood what was meant with most of the sentences. However, he had a raw score of correct items. His performance with irregulars was very poor as well, whereas with regulars he performed mostly well.

4.3.2 Results – Action word test for irregulars

The picture based action word test was much easier to solve for the subject than the context based test procedure. In total both subjects were also performing poorer on irregular action verbs than on regular action verbs.

Sandra was significantly worse in producing the correct preterite form (1/5) than producing the right perfect form (5/5).

Regarding frequency effects she performed well on frequent regular verbs. Added to that, she had a score of 1 correct from 5 irregular infrequent action verbs as well as regular action verbs.

She performed worse for the infrequent preterite form as this form needs to be stored in the lexica as a whole.

In the preterite group that was elicited, Sandra shows an overgeneralization for high frequent irregular forms.

Martin performed surprisingly well in the production of the correct preterite form (3/5) and the right perfect form (5/5).

Concerning frequency effects he performed good on frequent regular verb. Apart from that, he had a score of 1 correct from 5 irregular infrequent action verbs as well as regular action verbs. He performed quite well for the infrequent and frequent preterite form, which shows a variation in the performance in comparison to Sandra. There were less frequent errors made for overgeneralization in irregular form.

5. Working Memory, mathematical reasoning ability and digit-span

Apart from language acquisition of irregular verb structures working memory (WM) is moreover used in mental calculations problems [83], where we need a temporary store for retaining the carry unit, which is in written arithmetic problems the page itself that serves as storage.

Mental calculation involving more than two units requires several carrier operations. The question is how is it possible to calculate problems, such as $455 + 73$ or $674 + 487$ in multi digit addition?

This chapter was added to the thesis because the digit-span digit-span test is a measure to determine working memory ability.administered [108]Added to that, a test on mathematical reasoning ability was conducted within the thesis.

WM relates to mathematical reasoning, because WM is used for information storage and manipulating information, thus being essential for the mathematical reasoning ability.[]

5.1. Working memory – state of the art

As presented in a study by Hitch mental calculation problems as above are solved by their participants sequentially by calculating the intermediate results in stages of tens, hundreds, thousands depending on the strategy used. The all-over task of the working memory (WM) is however, to retain the previous carrier unit in storage to have free capacity to calculate the next stage and then connect the two results together. Not surprisingly, Hitch and his colleagues showed that the more carrier operations are involved, the more time is needed in total for the calculation[48].

Performance in mental rotation problems was used by a number of scientists to measure individual differences in working memory capacity [84]. Moreover, it was a question of interest, what kind of working memory components (Visio-spatial sketchpad, phonological loop or executive central) are needed at what stage of the mental calculation.

In a series of experiments Dark and Benbow [95] investigated the individual capacity of WM in participants with high mathematical or high verbal ability. Results showed that individuals scoring higher in the mathematical group had enhanced capacity for numerical information, whereas individuals scoring higher in the verbal group had enhanced capacity for words. Apart from that participants with enhanced capacity for numerical information were using the Visio-spatial sketchpad more efficiently, which plays an important role in mental arithmetic's.

As it has been pointed out by Ashcraft the Visio-spatial sketchpad is obligatory in mental calculation tasks to store visual characteristics, such as the number itself and column-wise positional information to keep track of the carrier unit. Furthermore, it has been demonstrated by Ashcraft that the Visio Spatial sketchpad can't operate in isolation. Thus, it involves the phonological loop to contribute in retaining the numerical information [96].

The important role of the phonological loop was underlined by Logie et al. [97], who studied mental calculation. The participants were asked to mentally calculate visually or auditorily presented two digit numbers. Results showed that the retention of the carrier unit and intermediate results are due to sub vocal rehearsal in the phonological loop. However, the phonological loop seems to be impaired in Williams Syndrome subjects [55] Therefore it makes sense why WS people have considerable difficulties with mental calculation tasks. Apart from that Logie et al. discovered that people get distracted during mental calculation by processing random information in the central executive. In addition to the phonological loop (and the Visio-spatial Sketchpad) the central executive plays an important role in retrieval of procedural and declarative arithmetic knowledge.

As lined out, mental calculation affects all components of the WM. This has been summed up in the so called "triple code model" of numerical processing proposed by Dehaene and his colleagues. [85]: They claim in their model that in mental calculation numbers are represented in three different codes:

- First, numbers are represented as a visual arabic code that is a string of digits on an internally visio-spatial sketchpad.

- Second, there exists a verbal code to each phonological representation.
- Third, there is an analogical spatial representation representing the magnitude of the numbers.

It is assumed that in mental calculation tasks all three codes are needed in parallel to process numerical information. However, the triple code model allows to attribute involved components of the working memory to its parts. For example the Visual Arabic code and the Analogue magnitude code need the Visio-spatial sketchpad, whereas the phonological loop retains information of the verbal code.

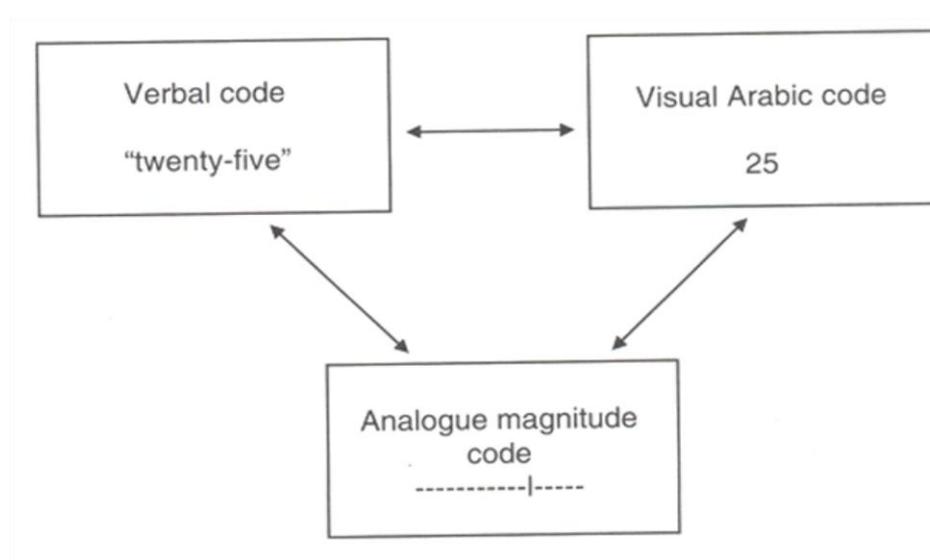


Figure 4: Dehaene's Triple Code Model

5.2 Acquisition of numerical skills in typically developing children

Numerical cognition in the normal brain has been investigated a lot in recent years by researchers like Gallistel and Gelman [93]. Additionally, the help of functional neuroimaging methods such as EEG, PET or TMS made a great contribution and led to the development of differ-

ent theories. For example one theory proposes that number processing is a module that is innate and is responsible for quantity, ordering amounts by size and detection of changes in numerosity.

Due to brain imaging studies another theory has been developed based on the claim that numerical cognition is based on two representational systems: [86]

- First, an approximate language-independent system, and
- second an exact language-dependent system.

The approximate system works analogue, where the variability of the signal is proportional to the size of the represented magnitude. The exact system on the other side is represented by an integer-list of numbers in natural languages. The systems are assumed to work separately in the brain.

At what age does numerical cognition develop in children?

This question has been addressed by Starkey and Cooper in their studies [89]. They have observed that even newborns are able to discriminate between 2 versus 3 dots. Going even further in their studies they have shown that 5-months olds are able to keep track of simple numerical operations, such as addition and subtraction. Although, they can't manipulate greater numbers than 3. Furthermore, they are also not successful in discriminating between 4 and 6 dots.

Based on these rather surprising results, two different theories have developed how infants process numbers:

- The Object File model
- The Analogue model

The object file model assumes that each object is represented by a separate non-numerical symbol. Each additional object is represented by the generation of a separate file in the brain. The amount of object-files can't exceed three or 4 objects [98].

The analogue model challenges the Object File model, as it claims that infants are able to discriminate between 8 vs. 16 dots by the age of 6 months, but they can't discriminate 8 vs. 12 dots. Furthermore, 11 months old infants can distinguish the ordinal relationship between 4,8 and 16 dots. This gives evidence that infants at this age are able to process numbers greater than 4. This model concentrates on the developmental ontogenetic view but doesn't explain the limita-

tion in number processing found at the age of 5 months. The advantage of the analogue model however, is that it is higher-level regarding the discrimination ability and explains the impairment of number in adults [98].

5.3 Acquisition of numerical skills in WS

Most WS individuals experience considerable problems with number, which is closely linked to their Visio-spatial deficits [88]. However, mathematical abilities have been addressed only by a small number of researchers. One theory is that only some and not all abilities in mathematical reasoning are impaired in WS. In fact for mathematical reasoning we require distinct neurological representations for the verbal components of numerical reasoning [87]. Mathematical reasoning can be tested for example a Test of Mathematical Abilities (TEMA-2, Ginsburg & Baroody, 1990), which has been used for examining mathematical abilities.

Furthermore, it has been observed that mathematical ability is selectively damaged due to the rather weak spatial abilities. Mathematical tasks that rely on the representation of numerical magnitude are more impaired than the ones that rely on verbally encoded number. In line with this findings are observations from Paterson et al. [91] that number estimates and the symbolic distance effect are especially impaired in WS as they are linked to numerical magnitudes. In the acquisition of numerical skills, it has been seen that WS children with a mean age of 9,7 years showed estimating abilities of dots that can be compared to 4 year old typically developing children.

Apart from this it has been claimed by Ansari et al. [90] that understanding of cardinality in 6 to 11 year old WS children matches to typically developing 3 to 4 year olds.

But where the impairment in mathematical reasoning is located neurologically? Concerning this question it was observed that numerical problems in particular tasks that require a mental number line are associated to abnormalities in parietal areas found in WS. On the other hand, what is also important is that mathematical understanding precedes relatively normally given a reasonable introduction and education to number routines. However, some mathematical routines are not introduced to WS individuals, such as multiplication routines or subtracting above zero.

To summarize it can be said that the WS profile in number is consistent with the overall pattern of strength and weaknesses found in the genetic disorder. The findings made are mostly in line with the spared verbal abilities and the impairment on spatial tasks [16].

5.4 Phonological short-term memory and digit-span

Phonological short-term memory is taken in account in the scope of this thesis, because the phonological system, especially the phonological loop, plays a role in the computational model as a rehearsal component. In addition to the phonological system, the digit-span is mentioned, because it is a common measure to test phonological short-term memory.

When taking in account the phonological system, it is needed at first to define the term phonological short-term memory, also called auditory short-term memory. The phonological system plays an important role in the acquisition of language skills in childhood, enabling children long-term learning of new words or sound structures that are crucial for language acquisition [44].

In the standard model of short-term memory from Atkinson-Shiffrin [45] the term short-term memory has been defined and taken into account in greater detail. According to Shiffrin a basic property of short-term memory is that it is better suitable for words, which can be rehearsed rapidly than words that take longer for rehearsal. Input information enters into STM and if repeated by rehearsal it can enter into LTM. A decay of the activation in STM, resembles the forgetting process. This decay can be prevented by repeated rehearsal. This repeated rehearsal is simulated in the ART model, where the input pattern is repeatedly processed via a connection between the recognition layer and the comparison layer.

In WS the short-term memory store is relatively “spared”, if not to say a strength of WS subjects. Evidence is given, in a study of Mervis et al., where auditory short-term memory is matched on chronological age [46]. It shows that 79% of WS subjects have a phonological short-term memory within normal range, meaning the digit-span has a mean value 4.6 in comparison to DS children that have a digit-span of 1 to 3 digits [47].

5.5. Study 3: Digit-Span

5.5.1 Introduction

In addition to the studies on language there was made a testing on the digit span of the WS children. It was conducted as in language the amount of syllables retained also plays a role, as it can be seen in the Mottier test. The raw value of the digit-span test was compared to the Mottier test.

5.5.2 Subjects

The subjects tested were the same as in the previous two studies on language. Thus, they will not be described here again.

5.5.3 Methods

The digit-span measure is a common measure to assess phonological short-term memory abilities. That's why there is the connection made between phonological short term memory and the digit-span measure in the beginning of this chapter.

During a digit-span task participants are required to read a series of digits e.g.5-2-4-1 and repeat them after a short break. When the repetition has been successful one digit is added to the list. The length of the longest list is called digit-span [104].

Figure x: Digit-span Test

5.5.4 Results

Sandra performed well until she reached 3 items in a row in the digit-span test. She achieved a raw value of 12 correct items. Martin performed with a raw value of 18 correct items, whereas he performed quite well with some 3 digit spans as well.

By comparing the results it needs to be emphasized that it is difficult to set them in relation. This will be taken into account in the discussion section.

5.5.5 Discussion

Following the different results that were obtained as a digit span measure and in the Mottier test the question needs to be asked, whether both two tests really do measure the same memory “span”.

Whereas the Mottier test measures more an auditive span of syllables, the digit span test actually measures a span of numbers. What is measured with the Mottier test is the phonological information that is retained while the digit-span test measures the number items that are retained in memory.

Meaning in the Mottier test the syllables are longer and obviously more difficult to retain than just numbers items.

Both tests can not be compared in a valid way to each other.

6. Computational modelling

Computational models have become increasingly important as a tool in Cognitive Science, not only to investigate changes within cognitive development, but moreover to simulate normal development and deviations in development [58].

Models that belong to the connectionist paradigm have some initial parameters that should be taken care of at the beginning:

- Initial architecture of the model e.g. three or two layer architecture
- Dynamics of the processing units
- Choice of Input – Output representations
- Type of learning algorithm
- Nature of the training set

A major advantage of computational models is that they allow a more appropriate representation of the developmental processes, thus, offering a good possibility for modeling developmental disorders. Another benefit of using computational models arises from the fact that developmental disorders as well as acquired disorders are interpreted within the same framework. This concerns a big debate going on, whether certain language components are acquired or developed during life.

Using a computational framework that entails developmental and acquired deficits allows us to investigate the cognitive system of disorders, such as WS much better. Modelling developmental disorders allow to illustrate components that develop more independently, whereas modelling acquired deficits show the structure of the adult system.

A disadvantage in computational frameworks is the validity of the whole cognitive system as most models take only a subsystem in account. The aim however, is to bring several connectionist subsystems together and integrate them to make predictions for the whole.

6.1. Why build a WS model and match the model to atypical empirical data?

The ultimate reason for simulating a developmental disorder affecting language, such as in WS is that the model perspective provides a good opportunity for understanding developmental disorders. One important reason is that the developmental process itself plays an important causal factor. Moreover, the computational modelling part is an important tool to study atypical processes of development in a complex surrounding by varying different parameter settings in the setup of the models. Modelling language aspects on a computational basis, enables to compare advantages and disadvantages of computational models that explain the behaviour of Williams syndrome. Finally, modeling illustrates another point of view in the rather theoretical debate on Williams syndrome past tense generation.

Given that assumptions of the cognitive deficits and manifested behavioral deficits are well understood and implemented as such, another question facing the interdisciplinary context, is how the simulated deficit can be brought into a broader connection with the experimental results.

The question to what it comes down is:

What parameters do we have to adapt in order achieve a similar output as in the experimental design?

As WS has some developmental delays in certain cognitive areas there is a problem in matching the simulation data to the empirical data. This means that empirical gathered data sometimes shows wide variations, between what is actually described in literature.

WS subjects have a rather spared short-term memory (STM), whereas the long-term-memory (LTM) and Visio-spatial memory is impaired [61]. However, in connectionist models STM can't be taken in account, as it doesn't represent the real STM in medical terms.

According to Karmiloff-Smith and Thomas et. al. in Williams syndrome there is “a multiple delay going from syntax to morpho-syntax, which lies behind vocabulary in the end. That's why one possible solution is to match the model's performance against chronological age (CA) or

verbal mental age data. What we can match is the model's past tense performance against CA under the condition that when the level of regular verb performance is controlled for, irregular verbs fall in line the baseline condition.” [59]

What should be emphasized here is that the matching between empirical data and the obtained data in modelling should be taken care of to make a comparison between empirical obtained data and modelled data in the end.

Added to that, it is important to compare these differently obtained data as we have used different methods to gain this data.

6.2 Connectionist Models of cognitive processes

Connectionist modelling has become increasingly important, due to common particular features in neural networks that can be observed in many cognitive processes as well.

These are for instance:

- They perform well after minor damage to the input units. They perform still reasonable, if the input is very noisy e.g. Artifacts or inaccurate sets of data.
- They allow the retrieval of memory. Based on these properties neural networks have become a popular model in order to simulate the behavioral output in Computational Cognitive Psychology or Computational Linguistics.
- They provide explanations for cognitive phenomena and develop predictions as far as the behavioral output is concerned.

That is why computational modeling of cognitive processes has been encouraged by two scientists namely Rumelhart, McClelland and the PDP Research Group: [60]

Connectionist modeling aims for a connectionist system that is used when learning is needed. For example, in a two-layered neural network it is possible to implement the Hebbian learning rule. Thus, by using connectionist models it is possible to simulate cognitive processes.

Apart from that, modeling cognitive processes deal with the way how knowledge is represented and processed in the neural network. The principle mechanism in neural networks or connectionist systems, is that knowledge is distributed in parallel across the network.

However, this major principle is in sharp contrast to many cognitive models, where information processing is serial. The disadvantage of serial models is, that they are not immune to damage done, meaning input units react immediately to noisy input signals.

6.3 Lesioning the model

When simulating atypical development, such as the acquisition of language in WS there are three possibilities to achieve this state:

- To remove a node,
- To remove a connections,
- To adapt the Learning Algorithm.

Firstly, nodes are removed.

For example, hidden units can be removed. Hidden units are used to recode the input units, meaning they serve as a representation for the inputs. There maybe several layers of hidden units depending on the architecture of the model. However, the amount of hidden units is quite important in the WS network.

In general, how many hidden units are manipulated depends on several parameters:

- the numbers of input and output units
- the number of training epochs
- the amount of noise in the targets
- the complexity of the function or classification to be learned
- the architecture
- the type of hidden unit activation function
- the training algorithm

As a network architecture a simple recurrent network (RN) also called "Elman network" was used. It is a three-layer network with the addition of a set of "context units" in the input layer. In a RN there is a feedback loop from the output back to the input units.

According to Thomas et al. [59], if the number of input units is too low, the error rate is higher. On the other hand, the error rate is lower, if the number of output units is too much, which is eventually leading to an over-trained network.

Secondly, the number of connections are removed.

A modification of the connections results in a network that is lesioned as well. When removing connections this can be done either by randomly removing them or by systematically removing them from hidden units. When a hidden unit contributes to a task, it is better to keep the corresponding connections. Whereas, if a task is very different from another task causing an interference, it will be more efficient to remove the connections that each hidden unit only contributes effectively to a single task [63].

Thirdly, the learning algorithm is adapted.

The learning algorithm is of great importance, as it is capable of teaching the network how to learn. For example in the Seidenberg and McClelland model the learning algorithm consists of simple back propagation. The advantage of back propagation is that the error is propagated back towards the origin of the error and then the weights are adapted again.

6.4 Modelling a double dissociation in language

In cognitive psychology the identification of double dissociation as it can be seen in Figure 5 means that a patient can perform process A, but not process B and another patient, who can perform task B but not task A. In mathematical terms it means: A and not B – not A. [64]

Thus, it can be said that the cognitive processes A and B are independent from each other.

	Process A	Process B
Region 1	Deficit	No Deficit
Region 2	No Deficit	Deficit

Figure 5: Double dissociation

P. Broca and C. Wernicke independently patients, who showed a double dissociation of language production vs. language comprehension. Broca's patients produced language clearly, but they had an impairment in understanding it. This pattern of impairment in semantics can be the result of a posterior lesion in adults.

On the other hand Wernicke examined patients that were able to understand language but had an impairment in production, meaning that patients rely a lot on gestures and indirect speech signals. In these days, these etiologies are known as Broca's and Wernicke's aphasia.

Not only in linguistics double dissociation phenomena are seen as an indicator for the modularity of language and that language is rather independent. When neuroscientists speak of modularity the mean brains that are structured with cells, columns and layers, where each 'module' has a separate function in information processing.

Either developmental or acquired deficits can be modelled by connectionist system. Furthermore, it is widely popular to test the validity of a model by implementing dissociations in a working model of language. As a consequence a variety of acquired impairments are studied in connectionist modelling, such as aphasia or dyslexia.

Apart from connectionist models of acquired impairments we can use connectionist models to simulate a development in language, such as reading models or models of past tense acquisition have been doing. A model for normal and impaired word reading in adults was developed successfully by Plaut, McClelland, Seidenberg and Patterson [65].

6.5 Language Models for Reading

The understanding of normal and impaired word reading has been examined thoroughly by M. D. Plaut et al.[70] for example. The Plaut's model for reading is mentioned here, because the connectionist network constructed is based on the Plaut model.

Thus, some known models will be represented in the following to get a short overview on what has been developed, but at first the question should be raised up:

What differentiates a skilled reader from an impaired reader?

To investigate the question further, the relationship of the mapping between the orthographical input and the phonological output has to be taken into account.

In basic there are two general basic models that lay beneath:

- the dual route model of word reading
- the single route model of word reading

Connectionist models are referred to as single route models. Their basic characteristic is a single mechanism is responsible for lexical storage and rule-based learning [66].

Furthermore, there is no word storage component for lexical or individual words, for example past perfect of irregulars. The principle of a single route model is that connection weights are set by the model that learns from experience. In general, single route models learn by exposure to a distinct data set [67]. A major disadvantage arises from the fact that these models are

bad for pronouncing non-words. In cognitive psychology a number of single route models for reading have developed until now.

The first model solved the problem of many orthographic characters mapping to one phonological sound like in English language “ough”, was postulated by Sejnowski & Rosenberg. The three layer neural network called NETtalk pre-processes training data by inserting special continuation characters into the phoneme strings to align the letters and phonemes. The disadvantage of the model is based on the alignment procedure [68].

Rumelhart & McClelland used a set of distributed Wickelfeatures in which each phonetic representation of the verb stem is translated to. The Wickelfeatures are position-independent, context-dependent phonetic features and represent a fine-grained but somewhat restricted representation of phonemes present in the English language [106]. This over goes the problem of aligning the letters and phonemes, but makes the interpretation of the networks output difficult and presents difficulties in understanding the nature of the internal representations. This model is restricted to mono-syllabic words and performs poor on non-words [69].

The already in the beginning mentioned neural network for reading has been posed by Plaut et al. [70], consisting of 108 orthographic input units, consonant, vowel and final consonant clusters and 57 phonological output units. The model performs well at learning the training data and at reading non-words, but is still restricted to mono-syllabic words.

Thus, the trend has gone in favor of dual route models that have a separate unit for the lexical processing and the syntactical processing.

The classical approach of the dual route model distinguishes between a lexical and a non-lexical component [71]. The non lexical route contains the grapheme-phoneme correspondence (GPC) describing rules how a grapheme is mapped onto a phoneme. For example the rule I -->/ei/, i--> /i/ contains the vowel sound for pronouncing the word MIND.

The lexical route entails an entry for every written word unless it is a non word. Looking up a word produces its specific pronunciation. For example as in Mind produces the correct /mInd/ and not /mind/.

A possible disadvantage might be the lack of double dissociation between exception words and non-words. If the non-lexical route is damaged non-words are impaired and can't be pronounced correct . If the lexical route is impaired, the result is a disability to recognize exception words. However, regular words can be pronounced in any case.

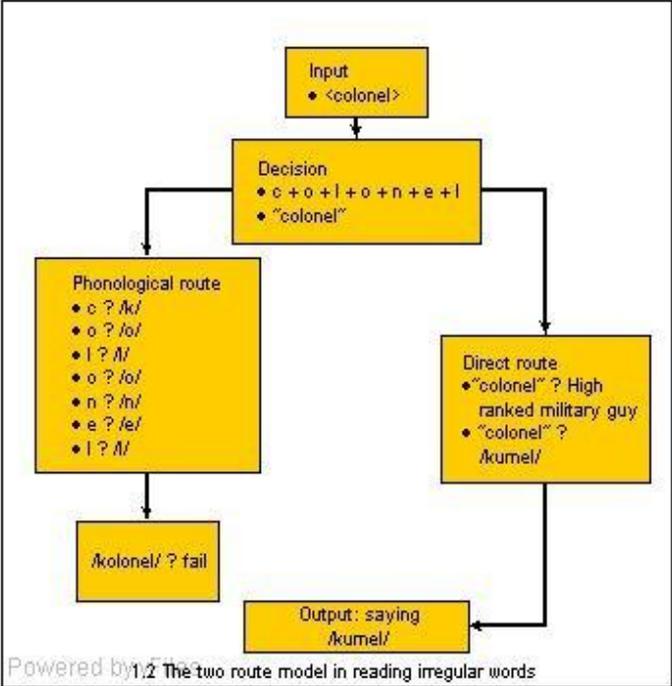


Figure 6: Dual route model for reading

A popular example for a dual route model is the Seidenberg and McClelland's model (1989). The aim of the model was first to show that a single mechanism can process regular and exception words and second that a mechanism is involved where activation is spreaded through the network. The model however is restricted for reading non-words. The emphasize lies on connectionist models, because it's easy to shown an impairment in the form of a lesion. However, other models exist in reading, such as the PDP (parallel distributed processing) approach . It assumes that cognitive processing is formed by the neural foundations. The approach is limited in its methods which are grounded only in Neuroscience.

7. Description of the Tlearn Model

In the following the model proposed in this thesis and its framework used will be described in a detailed manner. Apart from *Tlearn* there are other Software environments that can be used for modeling. In this case, the Software *Tlearn* has been used, because it enables easy going simulation of neural networks with a nice way of simulating other conditions.

7.1 Introduction to Tlearn Software

Tlearn is a neural network simulator tool that has been developed by Plunkett and Elman in 1997. It has been designed to run on various platforms, such as Unix, Windows and Macintosh and has the same user interface design across these platforms.

The startup menu of *Tlearn* looks very simple as you can see in Figure 7. After decompressing the downloaded *Tlearn* software from the webpage you can start modelling your network [62]. It is important to know that the Tlearn.exe in Windows has to be in the windows directory *tlearn* and the directory itself should be in the directory *programs*.

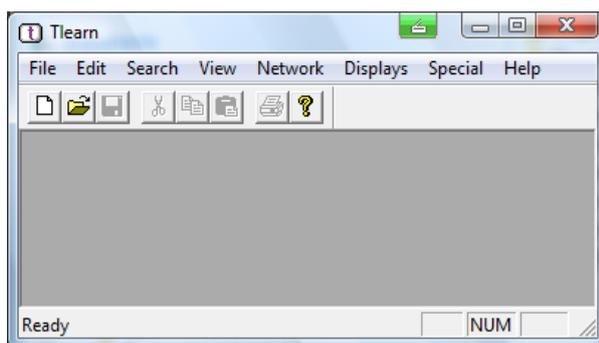


Figure 7: *Tlearn* User Menu

How to build the network model?

Starting to build a network, first of all we need a set of units that are connected by edges. In general, a networks architecture is represented by units connected to each other, such as in a

two layer or three layer network. Eventually, there are some hidden units in the middle layer between input and output units that can be manipulated.

A very simple network as shown in Figure 8 consists of two input nodes and two output nodes. The nodes are connected by lines also called edges, indicating the directing of the flow. In a feed forward network the flow goes from input unit to output units.

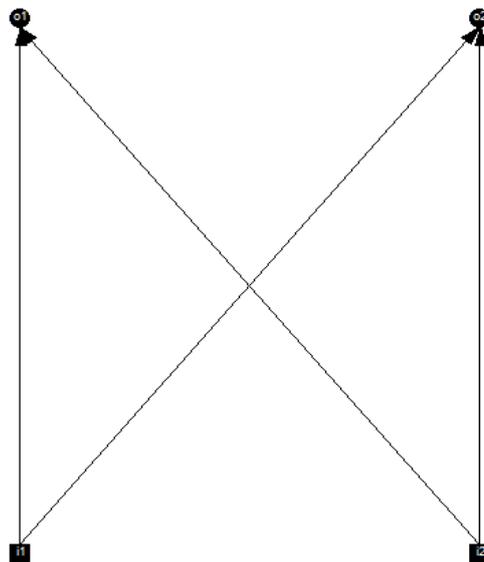
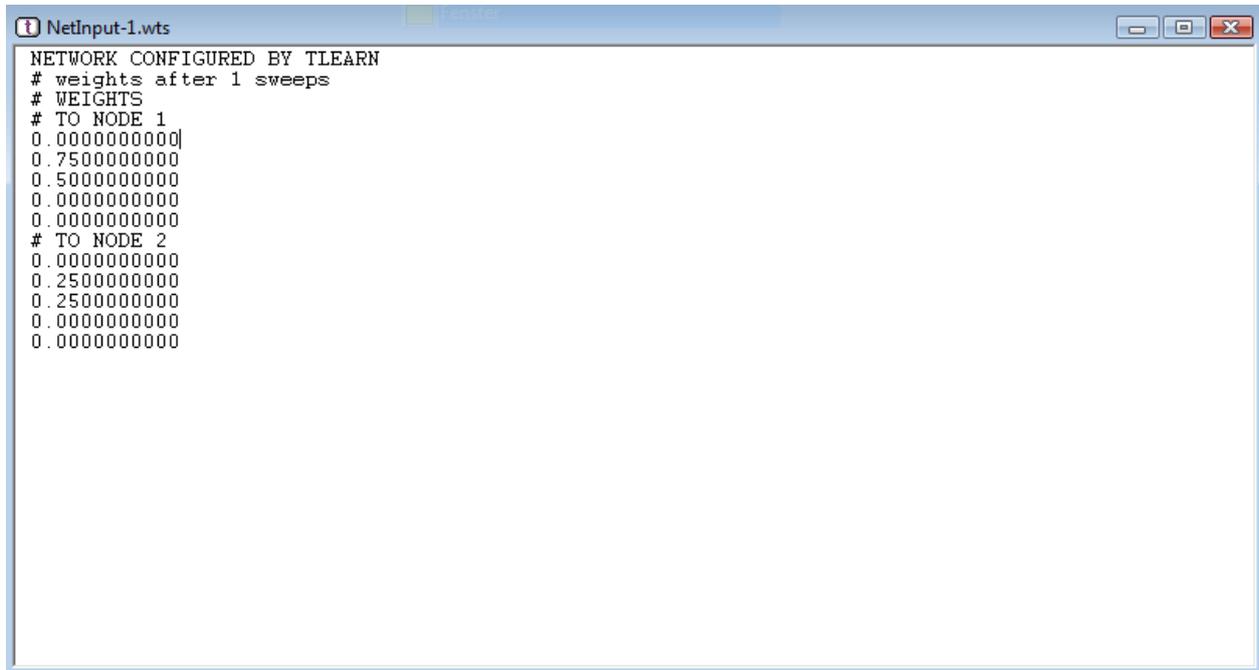


Figure 8: Feedforward Model of a simple network

There are also other kinds of network called recurrent networks (RN), where the information flow can be sent backwards again, initializing a feedback loop.

The net input of the network proposed above is based on the weight values (0,75;0,5) and the activity coming along with the weights. The net input (1,25) is based on the following formula:

$$\text{Net input} = (1.0 \times 0.75) + (1.0 \times 0.5) = 1,25$$



```
NetInput-1.wts
NETWORK CONFIGURED BY TLEARN
# weights after 1 sweeps
# WEIGHTS
# TO NODE 1
0.0000000000
0.7500000000
0.5000000000
0.0000000000
0.0000000000
# TO NODE 2
0.0000000000
0.2500000000
0.2500000000
0.0000000000
0.0000000000
```

Figure 9: Net input file containing the weights of each node

A crucial part in a neural network are the weighted connections in between the units. The weight enable learning by means of weight changes during the training process. The goal of a learning or training process is to adapt the weights, so that they respond appropriately to a set of cases. Each case has a certain input pattern (input layer) and as a consequence of the change in activation it generates a distinct pattern in the output layer. These patterns can be seen as n-dimensional vectors, where n is the number of units [107]. The representation in the form of a n-dimensional vectors has been chosen, because it is easier to model in a system.

The network's capability to learn is dependent on two different modes, such as

- training mode for learning the rule and adapting the weights and
- the testing mode where the network is tested with input pattern.

In *Tlearn* Weight adaptations can be monitored using the node activity tool (Figure 10)

The nodes in the network are represented by gray squares, where the activity of the output unit can be accessed easily via the menu *Node Activities – Displays*.

The node activity corresponds to the white squares inside of the gray ones, meaning that, if the gray squares turn white their activation rises. In Figure 10 below the node activity is zero, which can be seen, if the squares are still gray. The squares change to a white color, if the node activity gets the value one.

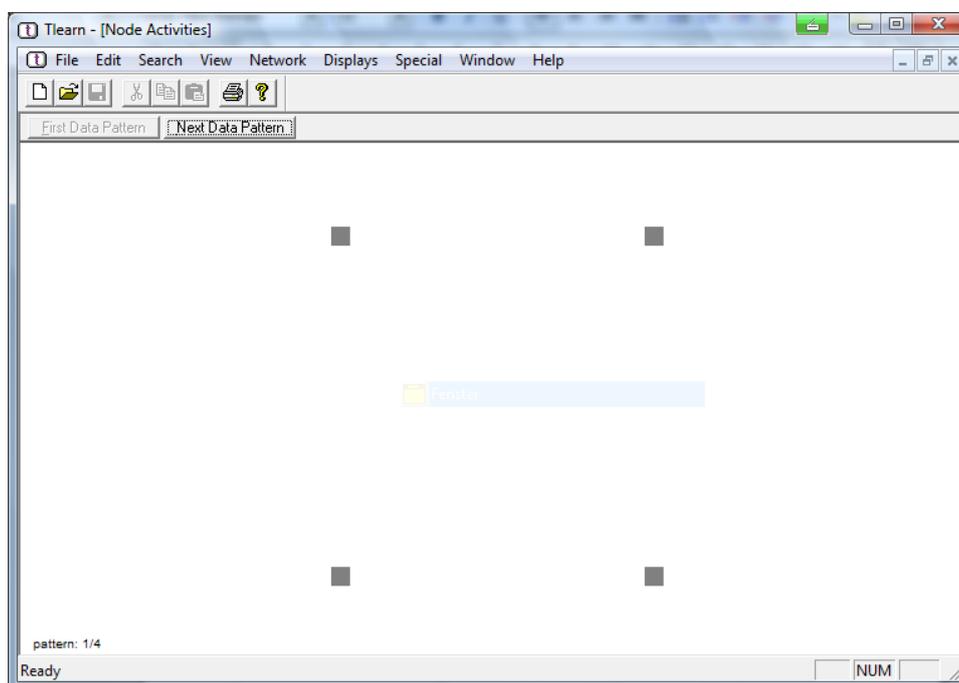


Figure 10: Node activity indicated by gray squares

7.2 Methods - Choice of learning algorithm

Being designed around the 1980's McClelland's and Rumelhart's model for word pronunciation and recognition has a major disadvantage; It is not able to learn.

Only in the late 1980's this lack of flexibility was overcome by the development of multi-layered networks that were able to use learning procedures, such as back propagation.

Learning procedures or learning algorithms are used to modify the individual network weights in a multi-layer network in order to associate an input pattern to a specific output pattern.

Back propagation was used further in the NETtalk model that has been created by Sejnowski & Rosenberg in 1987 to read English text. The model processes letter by letter in the input layer, receiving a local encoding of the target letter, as well as the three preceding and following letters. The output units on the other hand contain a local encoding of 23 articulatory features. Additionally, the model needs hidden units between input and output units to pre-process the information [68]. A disadvantage of back propagation is that it can be very slow as a learning algorithm. Thus, apart from back propagation one can use competitive, associative and reinforcement learning strategies.

7.3 Methods - Learning via Back propagation

In the back propagation procedure seen in Figure 11 the network compares actual responses against correct ones. At the beginning of each learning period the network is initialized with random weights.

Thus, the result at the output is most often incorrect.

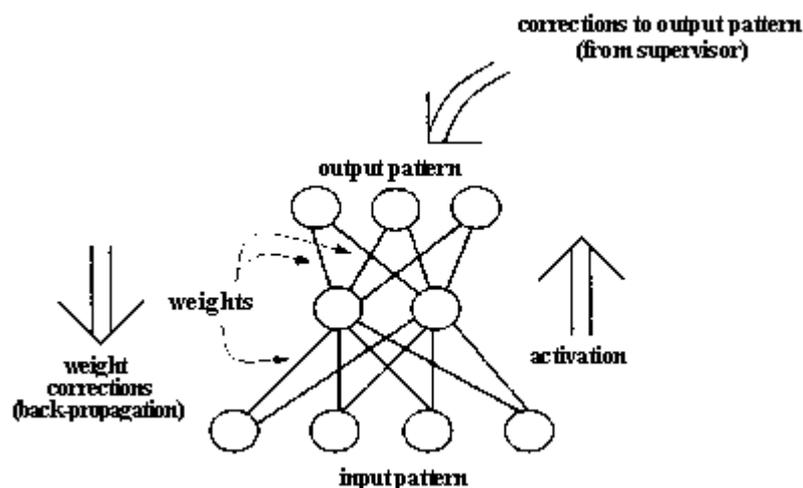


Figure 11: Back propagation procedure

What back propagation does is that it compares the incorrect pattern with the correct one and adapts each unit to produce the required pattern.

The formula of the error function is: [72]

$$\frac{\partial E}{\partial w_{ij}} = \frac{\partial E}{\partial o_j} \frac{\partial o_j}{\partial \text{net}_j} \frac{\partial \text{net}_j}{\partial w_{ij}}$$

Figure 12: Error Function in Back propagation

Accordingly, there are two different cases that are known:

- The neuron in the output layer is directly processing the output
- The neuron in the hidden layer then the activation can only be calculated indirectly

The adaptations of the weight between neuron i and j is defined as:

$$\Delta w_{ij} = -\eta \frac{\partial E}{\partial w_{ij}} = \eta \delta_j x_i$$

Figure 13: Weight adaptations

with

$$\delta_j = \begin{cases} \varphi'(\text{net}_j)(t_j - o_j) & \text{falls } j \text{ Ausgabeneuron ist,} \\ \varphi'(\text{net}_j) \sum_k \delta_k w_{jk} & \text{falls } j \text{ verdecktes Neuron ist.} \end{cases}$$

Figure 14: Delta rule in Back propagation

Whereas the factors are:

- Δw_{ij} changing of the weights w_{ij} between neuron i zu neuron j ,
- η fixed learning rate, with strength of the weight changes one can determine,
- δ_j error signal of the neuron j ,
- x_i input of neuron i ,
- t_j expected output of output neuron j and
- o_j the real output of output neuron j .

7.4 Methods - Learning via ART Algorithm

The ART (Adaptive Resonance Theory) algorithm from Grossberg and Carpenter is a method of analyzing information processing in vision, speech and neuronal development that [73]. A central principle of the ART algorithm is that it compares external input to internal output. It means that the weights change only when the external input is similar to the internal expectations.

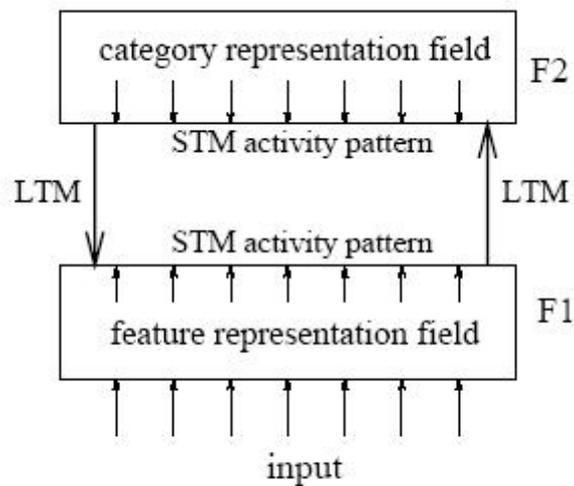
Thus, ART systems are well suitable for the on-line learning of large amounts of data and evolving databases, such as the mental lexicon is one.

ART algorithms belong to the group of match-based learning algorithms, therefore representing the contrary to back propagation learning, which is called error based learning [74].

Moreover, ART systems enable either rapid or very slow learning. This can only be achieved by a system that can adapt quickly to inputs, whereby the adaptive weights converge to an equilibrium when responding to an input pattern.

ART systems are declared to have a memory that is used for information storage. The ART memory is used in order to store new forms of inputs. Therefore, when new input enters at first the memory is searched. As seen in Figure 15 the model postulates the existence of a STM used for storing differing input patterns and a LTM that serves for classification and can be varied by the STM.

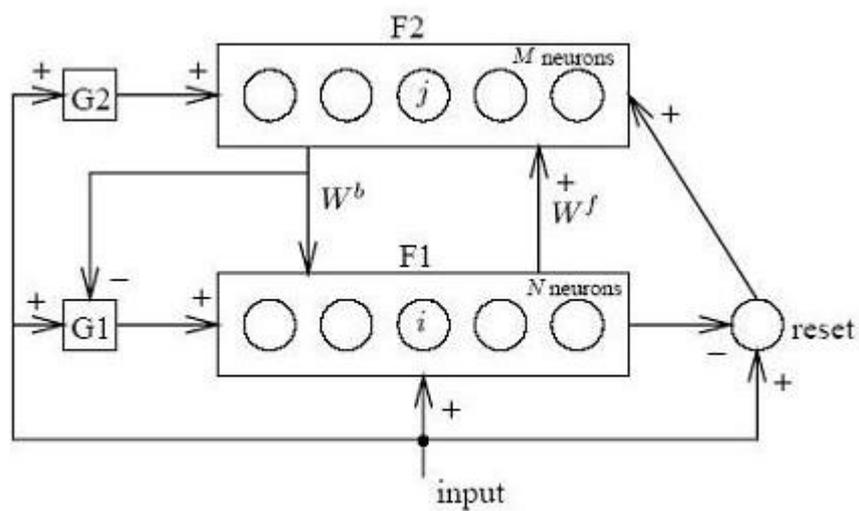
The two network layers are connected in a simplified model via the LTM component. When the input vector enters into the F1 layer it is transferred via LTM connection into the F2 layer for the classification of the input pattern. The determined matched classification pattern is transferred back into the F1 layer comparing if there is still a matching with the input. If there is indeed a matching between the determined matched classification pattern the information is amplified in the LTM. Otherwise the determined matched classification is discarded .



The ART architecture.

Figure 18: ART architecture containing LTM

The ART architecture can be seen as a 2 layer network of neurons with a comparison layer of neurons and a recognition layer of n neurons that are connected to each other via a weight matrix. In addition, there are two neurons $G1$ and $G2$ that serve as amplification factors and a reset component.



The ART1 neural network.

Figure 15: ART Network architecture

The comparison layer (F1 layer) receives the binary input vector and the output of the amplification neuron G1 and vector V. In order to allow the output vector s_i (Figure 16) to become active two of three inputs have to be 1, which is called 2/3-rule:

$$s_i = \begin{cases} 1 & , \text{falls } ((l_i \wedge v_i) \vee (l_i \wedge g_i) \vee (v_i \wedge g_i)) \\ 0 & , \text{sonst} \end{cases}$$

Figure 16: 2/3 Rule used in ART

In the recognition layer (F2 layer) the matching between the input vector to an existing or a new class takes place, which depends on the similarity of the input vector to the stored classification pattern.

Finally, only a neuron j is activated, if its input vector matches most to the defined classification pattern based on a similarity measure. The scalar product as a similarity measure is used.

$$u_j = \begin{cases} 1 & , \text{falls } t_j = \sum_i s_i w_{ij} = \max \\ 0 & , \text{sonst} \end{cases}$$

Figure 17: Scalar product as a similarity measure

A vigilance parameter that specifies the amount of similarity that must be retained in the matched pattern for resonance to occur.

A low vigilance allows a very broad categorization, whereas a high vigilance generates fine categories and a narrow categorization.

7.5 Testing the output of the model

If a network has been trained enough, it is tested with a set of input patterns and is ex-



Figure 19: Testing Tool in Tlearn

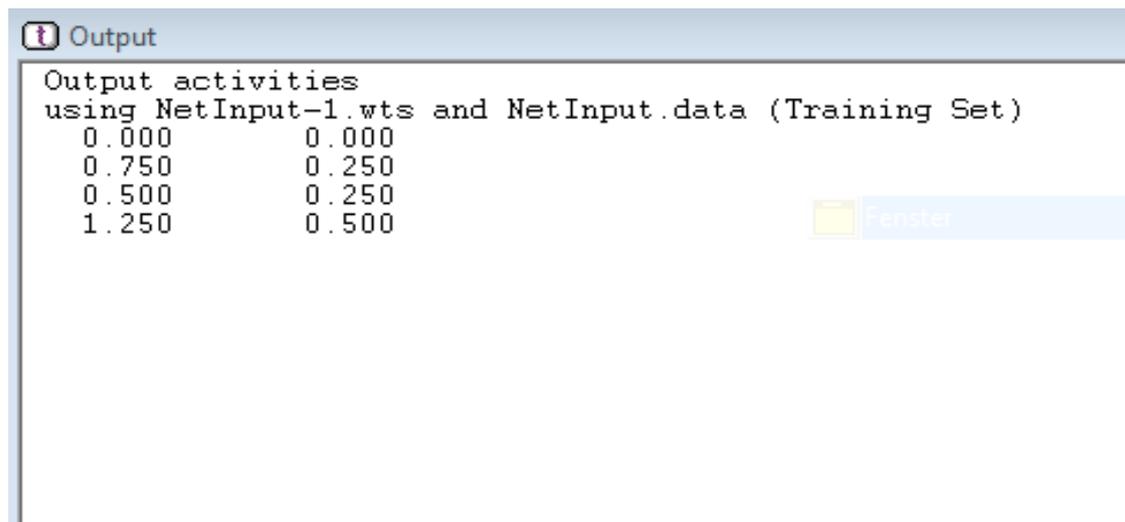
pected to respond with a distinct output pattern, as a consequence of the learning rule. The procedure needs to be done in order to avoid over-training and under-training of the trained network.

Therefore in *Tlearn* the weights file (NetInput-1000.wts) needs to be specified as it indicates the weights after e.g. 1000 epochs.

Taking a look at the weights defined in the NetInput-1000.wts file, you can see in Figure 9 the weights from node 1 to node 2. In the next step, the testing file has to be set according to the file NetInput.data.

The file specifies cases at the input, such as 0 0, 0 1, 1 0, 1 1. These four cases are distributed in the NetInput.data file. Last but not least the number of test sweeps is set automatically and is sent

to the output window after being calculated. After pressing *OK* at the settings and then go to *Verify network has learned*, the user obtains an output file as it can be seen in Figure 20 below.



```
Output
Output activities
using NetInput-1.wts and NetInput.data (Training Set)
0.000    0.000
0.750    0.250
0.500    0.250
1.250    0.500
```

The screenshot shows a window titled "Output" with a light blue header. The main content area displays text in a monospaced font. It starts with "Output activities" followed by "using NetInput-1.wts and NetInput.data (Training Set)". Below this is a table with two columns of numerical values. The first column contains 0.000, 0.750, 0.500, and 1.250. The second column contains 0.000, 0.250, 0.250, and 0.500. To the right of the table, there is a small yellow square icon and the word "Fenster" in a light blue box.

Figure 20: Output file showing the output activities

7.6 Discussion of the ART Algorithm

ART systems are used in several areas, such as in vision, speech and neuronal analysis, because of several reasons.

Adaptive resonance is successfully and widely used in face recognition, medical diagnosis, visual object recognition, musical analysis and much more [75]. Apart from visual perception, auditory identification and object recognition the ART principle is used in speech analysis as well.

Thus, it is quite reasonable to use a flexible algorithm for the acquisition of irregular verb forms in a network. One of the main advantages of ART is that TD language can be modeled better with ART, because the algorithm is more flexible than using simple back propagation.

The robustness of the long-term memory in the used model is influenced by the stability plasticity question.

The mental lexicon represented in the LTM behaves as described in the following:

- If a new verb is already known and no further class needs to be created. A new class represents a new category, meaning a set of elements that have a distinct feature in common and therefore belong to a class.
- On the other hand, if a new irregular verbs enter that is not stored in LTM a new class needs to be established, which shows the plasticity of the models behavior.

For non-words the algorithm starts to look into the mental lexicon, if there are already similar ones that can be found. If this is the case, the verb is treated as an already existing irregular verb. The model shows no a poor performance, as in most single and dual route models for non verbs.

Classifications of new categories once established cannot be deleted anymore, although they can be amplified if they are often processed.

However, the used ART model is not intended to process language in form of sentences. This comes from the fact that it is not possible to analyze combinations of words.

However, syntax is an essential part of language, which is a combination of words following a certain rule. The used ART model is not able to analyze combinations of verbs or words and therefore the model of WS language can only be used to model the language acquisition of irregular verbs especially.

8. Summary of Results

First of all, there will be a summary of the formulated hypothesis in the beginning of the study and their outcome during experimental research and modelling. The outcome of the results is represented in the shown pattern of result column.

Research Questions – Linguistic	Shown pattern of result
Are WS children sensitive to irregular verb flexion?	Poor performance for irregulars
Are there any frequency effects for irregular flexion?	Overgeneralization for infrequent irregulars
Research Questions – Computational	
Is ART algorithm better suitable for modeling typically developed language in the normal model?	Yes, because of flexibility to simulate the 2U shaped curve“ better
Is Backprop better suitable for modelling WS language in WS model?	Yes, because of overgeneralization effect

Table 1: Research questions and results

Regarding the normal model (NM) it turned out that back propagation induced slower learning of irregular verbs at the beginning of the training and slower learning at the end of the training. The over-generalization span is rather short for a model simulating typically developing language.

The usage of the ART (Adaptive Resonance Theory) algorithm in the NM showed fast learning at the beginning and slower learning at the end including a short overgeneralization span. An already mentioned property of the ART algorithm is its flexibility to be either very rapid or very slow.

Thus, for modelling language in the NM, the results show that an adaption of ART is better able to simulate the development of TD language.

An open issue still to be solved are the causal factors for the outstanding language skills in Williams syndrome language. How can language be preserved when mathematical reasoning is impaired in WS? Does it give an indication that language and reasoning are modularized in the brain and therefore are located in different hemispheres?

The model used for simulation, however doesn't explain to what extent language is a modular organic function. The created network based on adaptive resonance only takes in account the similarity of a novel verb or non-sense verb to an already existing one in the memory component.

8.1. Future Outlook

Although, we can measure the cognitive deficit in WS by means of IQ tests it is still unclear is, whether the spared language is related to an impairment, such as hyperacusis, or if it is related to a combination of impairments resulting from a genetic defect or other related factors.

What needs to be emphasized as well, is the great variance of different symptoms occurring in the WS profile. Along the study conducted the examined subjects showed both very big gaps in their phonological span or their mathematical reasoning abilities.

This leads to the question, whether it is possible at all to see a common pattern in a group of WS subjects?

Using models for language acquisition of past tense, allows to take these individual patterns in account and further investigate patterns by varying the constraints of an artificial constructed language model.

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