Difficulties in sounds and sentences

THE RELATION BETWEEN PHONOLOGICAL AND SYNTACTIC DIFFICULTIES OF TODDLERS WITH DEVELOPMENTAL LANGUAGE DISORDER

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Abstract

For children with a developmental language disorder (DLD), impairments in phonology and syntax often co-occur (Fey et al., 1994; Tyler, Lewis, Haskill & Tolbert, 2002). However, it is not clear whether, and if so how, difficulties in these domains are related. The current study examines the relation between phonological and syntactic difficulties in 45 toddlers with DLD, aged between 2;4 and 4;3 (M = 3;6). It comprises a concurrent and longitudinal examination of receptive and expressive phonological and receptive and expressive syntactic abilities.

Correlation analyses indicated that phonological and syntactic abilities of toddlers with DLD were related at concurrent time points within the receptive and expressive domain. Furthermore, repeated mixed effects analyses showed that improvement in expressive phonological abilities was related to improvement in expressive syntactic abilities, and that improvement in receptive phonological abilities was related to improvement in receptive syntactic abilities. Finally, a qualitative analysis was conducted to explore differences between toddlers with different phonological diagnoses. This analysis suggested that toddlers diagnosed with an inconsistent phonological disorder had poorer syntactic skills than toddlers diagnosed with a consistent phonological disorder, although further research is needed to address this issue. The results of the current study were used to compare four different theories on DLD, including the Bucket theory (Crystal, 1987), a grammatical theory (Rice, Wexler and Cleave, 1996), cascading theories (Chiat, 2001; Joanisse and Seidenberg, 1998), and implicit learning theories (Romberg & Saffran, 2019; Ullman & Pierpont, 2005). The results are mostly in agreement with the predictions made by the cascading and implicit learning theories.

This study contributes to our understanding of how different components of language interact during the language development of children with DLD. More specifically, it provides insight into how receptive and expressive phonological skills are associated with syntactic comprehension and production skills in toddlers with DLD. This study could have implications for clinicians and speech and language pathologists, as the interactions across phonology and syntax could be used in future interventions for toddlers with DLD.

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1. Introduction

To acquire language, children must learn the structures of sounds, words, and sentences of their native language. For most children, this happens automatically, effortlessly, and without explicit instruction (e.g. Brooks & Kempe, 2012). However, language is not acquired effortlessly by children with developmental language disorder (DLD). These children have impairments in the development of their language production or production and comprehension, although they do not have sensory, cognitive, or neurological deficits, an unfavourable psychological condition, or have suffered from deprived language input (e.g. Brooks & Kempe, 2012; Verhoeven & van Balkom, 2004). They often show difficulties in all language domains, including auditory perception, phonology, morphology, semantics, and syntax (Botting & Conti-Ramsden, 2004; Brooks & Kempe, 2012). Impairments in phonology and syntax often co-occur (Fey et al., 1994; Tyler, Lewis, Haskill & Tolbert, 2002), and it is therefore likely that these difficulties interact (e.g. Fey et al., 1994; Tyler, 2002; Tyler et al., 2002).

Potential interactions between phonological and syntactic abilities could have implications for the type of interventions speech and language pathologists should provide to children with DLD, and are therefore important to examine. Thus far, however, little research has been conducted on relations between phonological and syntactic difficulties of children with DLD. Therefore, it is far from clear whether, and if so how, these difficulties are related during language development.

The aim of the current study is to explore potential relations between phonological and syntactic comprehension and production abilities of toddlers with DLD. This study comprises concurrent and longitudinal examinations of relations between expressive and receptive phonological abilities and expressive and receptive syntactic abilities of toddlers with DLD. The concurrent analyses examine relations between phonology and syntax at two time points, although the syntactic and phonological tests are not always administered at the same time points. Therefore, the concurrent correlations are correlations between phonological and syntactic performances at two different points in development, although with the same time span in between these measurement points, see Section 4.2 for further explanation. The longitudinal analyses examine relations between phonological and syntactic change between these measurement points. The toddlers participating in the current study are diagnosed as having speech sound disorders (SSD) and suspected DLD. These toddlers will be referred to as toddlers with DLD, but bear in mind that they have SSD as well.

The hypotheses of the present study are based on different theories on the cause of DLD, which are described in Chapter 2, the Theoretical background. The theories described there are: the Bucket Theory (Crystal, 1987), cascading theories (Chiat, 2001; Joanisse & Seidenberg, 1998), a grammatical theory (Rice, Wexler & Cleave, 1996), and implicit learning theories (Romberg & Saffran, 2010; Ullman & Pierpont, 2005). All of these theories, except the grammatical theory, predict interactions between phonology and syntax, although they differ in the kind of interactions they predict. The different theories are discussed in the next chapter and compared to the results of the present study in the last chapters.

The current study can contribute to our understanding of how different components of language interact in atypical language development. A secondary goal is to compare different theories on DLD, based on the predictions they make about how phonological and syntactic impairments are related. More specifically, the current study provides insight into how receptive and expressive phonological skills affect syntactic comprehension and production of toddlers with DLD, and vice versa. This study could have implications for clinicians and speech and language pathologists, as potential interactions across phonology and syntax could be used in future interventions for toddlers with DLD.

2. Theoretical background

2.1 A model of language processing

2.1.1 A functional model of speech perception and production

To explore the potential interactions between phonological and syntactic difficulties of children with DLD, the functional model of speech perception and production proposed by Terband, Maassen, and Maas (2016) is used. In the subsequent sections, this model will be used to make clear how phonological and syntactic elements interact during speech production and perception. Furthermore, this model will be used in discussing and comparing the different theories on DLD, because it can make clear how these theories differ from each other.

The model by Terband et al. (2016) is based on the spoken language processing models by Levelt (1989) and van der Merwe (1997). Their model describes speech processing using a hierarchical structure with cascading activation, in which the output of one module is the input for the next module. Information is processed continuously and incrementally; multiple modules are active at the same time and a module can start processing input from the previous module before that one is finished. Additionally, the model contains self-monitoring processes at multiple levels, which are used to avoid errors in speech production. The model is shown in Figure 1 and describes the speech perception and production processes in an adult listener/speaker.

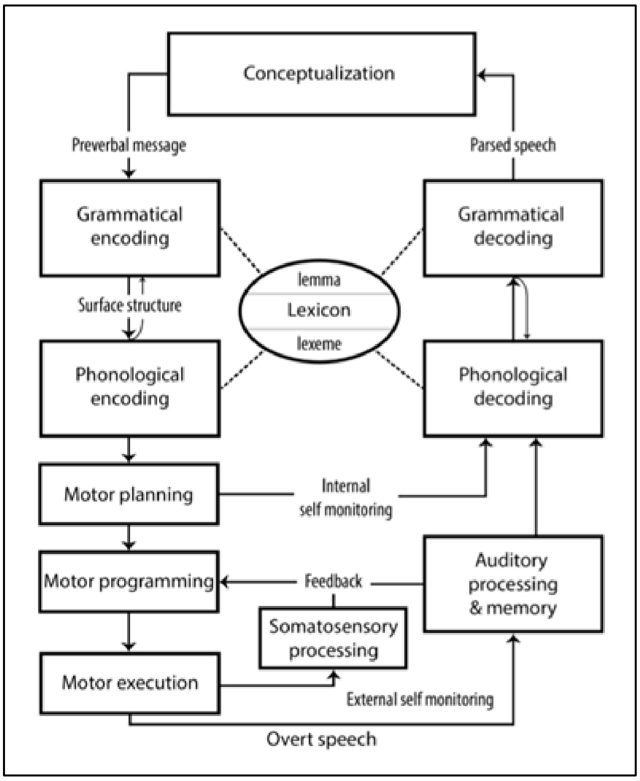

Figure 1. Speech processing model by Terband et al. (2016, p. 5)

Speech production starts with a concept a speaker wants to convey, which is at first a non-verbal message. This message goes to the grammatical encoding module, in which words, together with their syntactic structure, are retrieved from the mental lexicon. During grammatical encoding, the syntactic structure of a sentence is built using the grammatical properties of the words. The selected words are the input for the phonological encoding process, in which the sounds of the words are selected and ordered, in accordance with phonological rules. During motor planning, the articulatory movements are selected and ordered, and this information goes to the motor programming process, in which the actual muscle movements are programmed in order to produce the sounds. Finally, this motor program is executed by the speaker.

For speech perception, overt speech needs to be converted into a conceptual message. In the auditory processing and memory module, speech is recognized and differentiated from other sounds and stored in the short-term (phonological) working memory. Then, phonological decoding takes place, i.e. mapping recognized sounds onto words, and these words are activated in the mental lexicon. The meaning of the activated words is retrieved during grammatical decoding. Furthermore, in this latter module, the syntactic structure of the incoming sentence is parsed. Next, the sentence can be translated into a conceptual representation of the situation that is described.

Because the output of one module is used as input for the next module, all modules are connected. So, if something goes wrong in one module, the next module processes incorrect input, leading to difficulties or incorrect processing (Terband et al., 2016). For example, if there is a problem in the phonological decoding level, it is difficult, or perhaps impossible, to retrieve the correct word from the mental lexicon, and consequently, the grammatical decoding module cannot select the correct words and their syntactic structures. This in turn, means that it is very difficult to get the meaning of the words and to parse the sentence, which may lead to comprehension difficulties.

2.1.2 Development of processing modules

In adults, the speech production and perception processes are 'highly overlearned', and thus 'very robust' (Terband, Maassen & Maas, in press, p. 8). Small children, however, are in the process of acquiring grammatical and phonological rules; their language processing needs to develop into an adult-like system. This is shown in Figure 2. As can be seen, this model is a simplified version of the adult model; the encoding and decoding processes are not yet there. When the vocabulary of a child grows, the phonological system develops, resulting in a mental lexicon and phonological encoding and decoding processes (Maassen, 2002). This leads to the development of grammatical encoding and decoding processes, and finally to an adult-like language processing system.

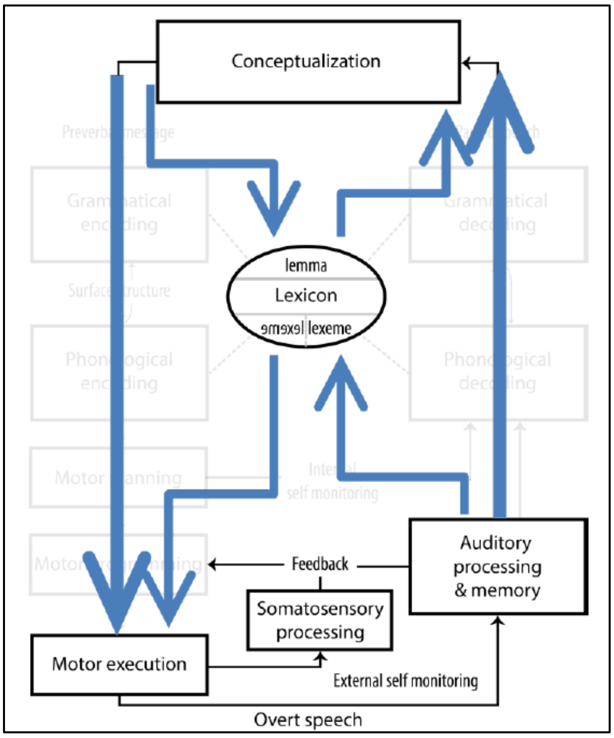

Figure 2. Model of speech processing in young children by Terband et al. (2016, p. 5)

The different processes develop simultaneously, and their developments interact (Nip, Green & Marx, 2011; Terband et al., in press). This means that if a child has a (developmental) impairment in one module, this influences the development of neighbouring processes as well (Terband et al., in press). For example, if a child has an auditory-processing deficit, this could also lead to difficulties on the phonological level, because a child cannot form correct and stable phonological representations based on reduced input. And a phonological deficit could in turn lead to difficulties in the next, syntactic, module. In other words, the model by Terband et al. (2016) suggests that the development of phonology and syntax interact.

2.2 Typical language development

This section briefly describes the phonological and syntactic development of typically developing (TD) children. The typical development in these two domains is relevant for understanding the difficulties children with a language disorder could have, and for a better understanding of how phonological and syntactic abilities might be related.

2.2.1 Speech perception

Children can understand speech before they produce their first words (Nijland, 2009), therefore, development of speech perception precedes the development of speech production. At first, babies are able to discriminate between sounds that do not exist in their native language. Between six and ten months of age, infants start to tune into their native language (Werker, 1989). Universal speech perception develops into more language specific perception abilities, which are needed for distinguishing phonemes, and thus recognizing words. To do so, infants must build stable representations of words (White & Morgan, 2008). These representations are especially needed to map meanings to words, but, for instance, also to detect grammatical categories. Infants can rely on multiple cues to segment words, including statistical regularities (Saffran, Aslin & Newport, 1996), rhythmic patterns (Thiessen & Saffran, 2003), phonotactic rules (Brent & Cartwright, 1996), and coarticulatory cues (Johnson & Jusczyk, 2001). Phonotactics are the rules that restrict on certain combinations or placements of sounds in a specific language (Zamuner & Kharmalov, 2016). In Dutch, for example, the cluster /br/ could be in word-initial position, but not in word-final position. Infants start applying phonotactic rules in word segmentation around the age of nine months, as was found by Friederici and Wessels (1993), Jusczyk, Friederici, Wessels, Svenkerud, and Jusczyk (1993), Mattys and Jusczyk (2001), and Jusczyk, Luce & Charles-Luce (1994).

2.2.2 Speech production

TD children follow a universal pattern in their phonological production development (Brooks & Kempe, 2012; Zsiga 2013). Infants must acquire the segments, phonological processes and phonotactic rules of their language, and errors in their production can be explained by their still developing phonological system (Beers, 2011). Between three and six months of age, infants start to try to imitate speech sounds. Around six months of age, the babbling phase starts, which is characterized by repeated consonant-vowel (CV) syllable structures. The first recognizable words are uttered around twelve months old. These words consist mostly of CV syllables and sounds and clusters of consonants are often simplified (Beers, 2011). Between the ages of three and four years, the phonology of TD infants becomes adult-like (Zsiga, 2013).

2.2.3 Syntactic comprehension

Before infants produce their first sentences, they already have some knowledge of syntactic structures, as is demonstrated by studies using an intermodal preferential looking paradigm (IPLP) (Golinkoff, Ma, Song & Hirsh-Pasek, 2013). In this paradigm, two pictures are presented to an infant together with an auditory sentence, and infants' fixations can indicate their comprehension of the sentence. An example of a study using IPLP is the study by Gertner, Fisher and Eisengart (2006), who found that 21-months-old infants can use word order to interpret transitive sentences. Furthermore, Kedar, Casasola, and Lust (2006) found that English-acquiring, 18-months-old infants were faster and more accurate in their fixations when they listened to sentences in which function words were used grammatically compared to when they listened to sentences in which function words were used ungrammatically. These studies indicate that young infants already have some knowledge of word order and function words, and that they can use this knowledge during sentence processing.

2.2.4 Syntactic production

As mentioned above, infants tend to produce their first word around the age of one. Roughly six months later, they start to produce two-word utterances (Zsiga, 2013). Between the second and third year of life, children begin to make longer and more complex utterances. In this stage, children's sentences consist of the most necessary words (Baker, Don & Hengeveld, 2013), and other words are often omitted. Verb placement develops from using infinitives as verb, to an 'optional infinitive stage', in which they sometimes use a finite and sometimes a non-finite form of a verb (Wexler, 1994), to using more complex predicates, including a finite verb in first or second position and a sentence-final verb (Wijnen and Verrips, 1998). Between the age of three and five, children learn many words of different grammatical categories, resulting in more complex sentences. Furthermore, children make fewer errors in word inflections (e.g. verbs, plurals, diminutives). Around the age of five, the syntactic production of children becomes adult-like (Baker et al., 2013).

2.2.5 Interactions between the development of phonology and syntax

The previous sections briefly described the typical development of phonological and syntactic abilities. The most obvious similarity between these linguistic domains is that both consist of patterns and structures; either of sounds and (representations of) words or of sentences. Children need to detect and learn these patterns and structures in order to build grammatically correct words and sentences. It is, therefore, likely that a statistical learning mechanism, which is used to detect and learn regularities, plays an important role in the acquisition of phonological as well as syntactic rules and categories (Wijnen, 2013).

There are not many studies that examined how phonological and syntactic development interact. However, an example of how phonological cues could influence syntactic categorization, comes from (infant) corpus studies that showed that, for example, verbs and nouns, and open- and closed-class words, differ in their phonological properties (Farmer, Christiansen & Monaghan, 2006; Monaghan, Chater & Christiansen, 2005; Monaghan, Christiansen & Chater, 2007). Nouns, for instance, tend to contain more syllables than verbs, open-class words are more likely to contain consonant clusters compared to closed-class words (Monaghan et al., 2005), and verbs are more likely to contain a fricative compared to nouns in Dutch (Monaghan et al., 2007). These studies thus show that grammatical classes differ in their phonological properties. Furthermore, Monaghan et al. (2005) conducted an artificial grammar learning experiment in adults to test the hypothesis that phonological properties are used to categorize words. The authors conclude that this result and the results of the infant-corpus studies suggest that infants might use phonological properties of words to make syntactic categorizations. Hence, phonological difficulties may impact grammatical acquisition.

2.3 Developmental language disorder

Children with a developmental language disorder (DLD, also known as SLI (Specific Language Impairment)) have impairments in the development of their language production or production and comprehension, although they do not have sensory, cognitive, or neurological deficits, or have suffered from deprived language input (e.g. Brooks & Kempe, 2012; Verhoeven & van Balkom, 2004). Children with DLD begin to talk later than TD children, and they produce fewer and less complex utterances. They often show difficulties in all language domains, including auditory perception, phonology, morphology, semantics, and syntax (Botting & Conti-Ramsden, 2004; Brooks & Kempe, 2012). Furthermore, it is found that children with DLD also show difficulties in more general cognitive abilities, for example speed of processing and working memory (Leonard et al., 2007).

Many preschool-aged children with DLD have impairments in both the phonological and (morpho)syntactic domain (Tyler et al., 2002; Fey et al., 1994). Studies that examined the phonological difficulties found, for instance, that toddlers with DLD have smaller consonant and vowel inventories than TD toddlers (Rescorla & Ratner, 1996), that they have different (Marshall, Harris & van der Lely, 2003) or underspecified (Claessen & Leitão, 2012; Criddle & Durkin, 2001; Maillart, Schelstraete & Hupet, 2004) representations of syllables, and that they have poorer perceptual skills (Hearnshaw, Baker & Munro, 2018; Cabbage, Hogan & Carrell, 2016). Studies that examined (morpho)syntactic difficulties of children with DLD found that they have difficulties in producing (e.g. de Jong, 1999; Spoelman & Bol, 2012) and comprehending (Rice, Wexler & Redmond, 1999) subject-verb agreement, that they prefer using simpler argument structures (de Jong, 1999; Spoelman & Bol, 2012), and that they have difficulties in interpreting complex sentence structures, such as reversible passives (Bishop, Bright, James, Bishop & van der Lely, 2000; van der Lely & Harris, 1990; Norbury, Bishop & Briscoe, 2002), and pronominal reference (Bishop et al., 2000; van der Lely & Stollwerck, 1997). These syntactic studies examined school-aged children, rather than toddlers, but they provide insight into the different syntactic difficulties children with DLD can have.

The diagnosis of DLD is based on exclusion criteria, and children with DLD therefore form a very heterogeneous population (de Jong, 1999). Several subclassifications are made based on, for instance, the type of impairments a child has, or on whether they show difficulties in language production or comprehension. This latter subclassification divides children with DLD in children who show mostly errors in production, i.e. 'expressive DLD', or in both production and comprehension, i.e. 'receptive DLD' (Leonard, 2009).

Dodd (as cited in Broomfield & Dodd, 2004, p. 137-138) made a subclassification of speech impairments of children with DLD. This subclassification is based on the type of errors a child makes. Dodd divided speech impairments into four subtypes; errors reflecting (1) phonological delay, (2) consistent deviant phonological disorder, (3) inconsistent deviant phonological disorder, and (4) an articulation disorder. Children who make errors that are typical errors for children of a younger age, are classified as having a phonological delay. Children who have a consistent deviant phonological disorder show errors reflecting the use of phonological rules that are not used in typical development, as well as phonological rules that are used in typical development. The difference with subtype (3) is that children with this latter type of impairment do not show the systematic use of rules, neither typical nor atypical rules. So, children with an inconsistent deviant phonological disorder make various errors that reflect an inconsistent phonological system. The last subtype is characterized by having difficulty in the production of sounds. Note that this subclassification is only made for phonological errors of children with DLD, but a similar subclassification could, probably, also be made for syntactic difficulties in these children, although this does not yet exist.

2.4 Interactions between phonology and syntax in children with DLD

Different types of potential interactions between phonological and syntactic difficulties can be distinguished. Top-down interactions would be effects of syntactic impairments on phonological performance, whereas bottom-up interactions would be effects of phonological impairments on syntactic performance. Based on the model proposed by Terband et al. (2016), interactions can be predicted in the process of speech perception (i.e. the receptive domain), and in the process of speech production (i.e. the expressive domain). Furthermore, relations between syntactic and phonological development could exist, which could be examined by, for instance, intervention studies, to see how improvement in one domain could lead to improvement in the other domain. Such effects are also known as 'cross-domain effects'. This section briefly describes studies that examined these different types of potential interactions.

2.4.1 Interactions between phonological and syntactic difficulties

Several studies examined how phonological properties of words or morphemes affect their syntactic production. Tyler (2002), for instance, points out that if a child cannot produce consonants or consonant clusters in final position, this affects verb inflection as well. Furthermore, multiple studies found other effects of phonology on verb inflection. For example, Blom, Vasic, and de Jong (2014) examined the production and processing of subject-verb agreement in Dutch children with DLD, aged between six and eight. They found that children with DLD omitted agreement inflection more often after plosives than after fricatives. Similar results were found by Rispens and Been (2007).

Leonard, Davis, and Deevy (2007) examined the influence of phonotactic probability on the production of past tense inflection in novel words in English children with DLD. Phonotactic probability was defined as 'the frequency with which the adjacent phonemes of the novel word appear together in actual words of the language' (p. 749), in which 'the language' refers to English. The authors presented novel verb stems, with either high or low phonotactic probability, to children and created a context in which the children had to produce these verb forms with the past inflection *-ed*. They found that children with DLD produced the English past tense inflection *-ed* less often in words with low phonotactic probability. Another study that examined phonological effects on syntactic inflection is a study by Montgomery and Leonard (1998). They found that children with DLD have more difficulty in processing 'low-phonetic substance inflections', including the English third person singular inflection morpheme, compared to 'higher-phonetic substance inflections'. These studies indicate that phonology influences the production and processing of verb inflection in children with DLD.

Gallon, Harris and van der Lely (2007) examined the influence of phonological complexity on the performance on a non-word repetition task in children and adolescents with DLD, aged between 12 and 20 years. These children (and adolescents) had syntactic and morphological impairments, but they did not have any speech or articulation difficulties. The authors found that the performance on the repetition task was correlated with the phonological complexity, indicated by syllable structure and prosodic structure, of the non-words in children with DLD. In other words, they performed poorer on phonological more complex words, while the performance of TD children, who were matched for language ability, was not correlated with phonological complexity. This finding shows that even though the children with DLD were diagnosed as having mainly syntactic impairments, they still have some phonological difficulties as well.

So, it seems that phonological properties of words and phonological abilities of children with DLD play a role in their syntactic performance, indicating the existence of bottom-up interactions. Furthermore, it seems that syntactic impairments also affect phonological performance, which suggests the existence of top-down interactions. All interactions found by the studies discussed in this section were interactions within the expressive language domain.

2.4.2 Cross-domain effects in intervention studies

Fey and colleagues (1994) hypothesized that a cross-domain effect between phonology and syntax could appear, because phonological and syntactic difficulties often co-occur in children with DLD. Moreover, they suggested that if these difficulties are related, providing training on a higher language level, i.e. syntax, could result in better performance on a lower language level, i.e. phonology as well. Therefore, they examined whether a grammar intervention for children with DLD, aged between 4;6 and 5;8, could lead to indirect positive effects on their phonological production. The interventions were based on four individual goals and the target forms were, for example, specific copula to express tense and number, pronouns (i.e. *he/she, he/him*), and expressing negotiation (i.e. *don't, won't*). The percentage consonants correct (PCC) was used as phonological production development index. The results indicated strong effects of the intervention on the grammatical skills of the children. However, the authors did not find facilitative effects of grammar interventions on the phonological development of children with DLD.

Feehan, Francis, Bernhardt, and Colozzo (2015) conducted a phonological and morphosyntactic intervention in two 6-year-olds with DLD. The children differed in whether they received first the phonological or the morphosyntactic intervention. During the phonological intervention, the focus was on the maintenance of weak syllables, word-initial /s/-clusters, and the production of clusters. The goals of the morphosyntactic intervention differed between the children, but consisted, for instance, of the argument structure of simple transitive sentences, the copula *is*, and the modals *can* and *can't*. The authors found that both children improved on the targeted domain after the corresponding intervention. They did not find specific cross-domain effects in global measures (e.g. total utterances, MLU, correctly pronounced words), although it could be that these measures were not sensitive enough to detect such effects. Therefore, the authors point out that their study 'can neither confirm nor refute the presence of specific indirect effects' (p. 67), although their results seem to be in agreement with the results found by Fey et al. (1994).

Contrastively, Tyler et al. (2002) did find an effect of morphosyntactic intervention on the phonological skills of children with DLD. They provided an intervention to pre-school-aged children who had deficits in both morphosyntax and phonology. The children were divided into two groups, differing in whether they started with a phonological intervention or with a morphosyntactic intervention. The children received interventions that were based on four of their own goals in morphosyntax and phonology, as was the case in the study by Fey et al. (1994). During the morphosyntactic intervention, the focus was often on finite verbs, including auxiliaries and regular and irregular past tense. During the phonological intervention, specific sounds or clusters were targeted. Tyler and colleagues found that the morphosyntactic intervention lead to improvement in the phonological abilities, measured by the

PCC, of the children, compared to a control group who did not receive intervention. However, the opposite was not found; the phonological intervention did not lead to improvement in the morphosyntactic abilities of the children. There was no effect of the order in which the interventions were given.

Tyler and Sandoval (1994) also studied whether interventions in different domains could lead to cross-domain effects. They examined the effects of a phonological intervention, a language-based intervention focusing on morphosyntax, and an intervention that was focused on both of these domains. Six pre-schoolers participated in their study, and were divided over the three intervention types. So, each intervention was tested on two children. The authors found that the language-based intervention did not lead to improvement in phonological abilities. The children who received phonological training, however, improved in their morphosyntactic performance. The children who received the intervention that focused on both morphosyntax and phonology also improved in both domains. This is the opposite result of the study by Tyler et al. (2002). However, because of the low number of participants per intervention type, the effects of the study by Tyler and Sandoval should be interpreted with caution.

To sum up, the studies described in this section differ in whether, and if so which, cross-domain effects of morphosyntactic and phonological interventions were found. The studies were all about the effects of treating phonological production on morphosyntactic production, and vice versa. No studies have been found that examined receptive cross-domain effects in (morpho)syntax and phonology. However, these studies seem to imply that there exist at least some interactions between the development of phonology and syntax. The next section contains several theories about the cause of DLD, which predict different interactions between phonological and syntactic abilities of children with DLD. The difficulties and intervention effects described in the previous and current sections are used to discuss these theories.

2.5 Theories about the relation between phonological and syntactic difficulties

2.5.1 Bucket theory

Crystal (1987) proposed a 'Bucket' theory of language impairment, in which interactions between different linguistic levels play a central role. Crystal used a bucket as analogy for language acquisition; a bucket grows during language development and is filled with 'linguistic water'. In children with DLD, however, the bucket contains holes, leading to the overflow of some water that was already in it when more water comes in. So, for example, 'an extra drop of phonology may cause the overflow of a drop of syntax' (p.20), leading to poorer syntactic performance. In other words, this model predicts a trade-off between different language capacities in children with DLD; when one domain develops, there are fewer resources left for other domain(s), resulting in a decrease or stagnation in performance in these domains.

Crystal (1987) conducted a case-study of a boy with a language impairment to provide evidence for his model. He found four interactions between different domains; interactions between (1) syntax and non-segmental phonology, specified as 'features of rhythm, intonation, and pause' (p. 17), (2) segmental phonology and syntax/semantics, (3) syntax and semantics, and (4) discourse and all other linguistic levels. Interaction (1) was characterized by less fluency in more complex utterances. The second interaction was shown by the fact that the more difficult utterances were used by the child, the more unintelligible was the production of their sounds, words, and phrases. The interaction between syntax and semantics held that in syntactically more complex utterances, the semantic information was reduced compared to syntactically less complex utterances. Interaction (4) was about the effect of discourse on all other linguistic levels, indicated by poor narrative skills.

The Bucket theory does not make the same prediction as the model by Terband et al. (2016). This model predicts that if one language process is deficient, neighbouring processes are affected in a negative manner as well. The Bucket theory, on the other hand, predicts that if a child with DLD becomes better in one linguistic domain, their performance in other linguistic processes stagnates or decreases. So, this theory predicts a trade-off between different linguistic processes, whereas the model by

Terband and colleagues predicts a positive correlation between different linguistic processes. However, the first two interactions proposed by Crystal (1987) could be explained by the model by Terband et al., because when the phonological decoding process receives more complex input (i.e. a complex grammatical structure), it is more likely to make errors, resulting in less fluent and more unintelligible utterances.

The Bucket theory cannot explain the interactions found in phonological and syntactic abilities of children with DLD, as were shown in Section 2.3.4. Additionally, this theory cannot explain why some intervention studies found positive cross-domain effects (Tyler et al., 2002; Tyler & Sandoval, 1994). It could be, however, that the children in the studies that did not find cross-domain effects would have shown negative effects in a linguistic domain that was not tested, such as semantics. This would fit the second interaction found by Crystal (1987), but this is not verifiable. Thus, the Bucket theory is not in line with the studies that were discussed in the previous sections.

2.5.2 Cascading theories

Cascading theories on DLD are theories that place the impairment of children with DLD in one language process/module and argue that this impairment results in difficulties in other language processes as well. These theories are in line with the model by Terband et al. (2016), that posits that impairments in one module lead to impairments in adjacent modules. However, Terband et al. do not make suggestions where the deficit of children with DLD originates, because their research is more about children with speech disorders, not with (speech and) language disorders. The current section describes two cascading theories on DLD; DLD as a phonological deficit, located in the phonological decoding process, and DLD as an auditory deficit, located in the auditory processing and memory module. Both theories thus locate the deficit in the speech perception process. There exist, however, other cascading theories on DLD as well, in which the deficits are located in other modules.

Chiat (2001) suggests that the impairments of children with DLD are caused by a phonological deficit. In typical development, children can rely on multiple cues to segment words from continuous speech, as is explained in Section 2.2.1. Furthermore, the context in which the utterance is produced can also be used to discover new words, guided by joint attention (Brooks & Kempe, 2012). For some words, including verbs, function words, and grammatical morphemes, context cannot be easily used to discover their meaning. Instead, one must detect the phonological form of such a word in different contexts and notice when this word can be used in order to discover its meaning. So, when semantic information is not available, children can, according to Chiat, only rely on phonological cues. However, when phonological processing is impaired, it is difficult to detect and form stable phonological representations. This, in turn, makes it very hard to discover the meaning of such "not observable" words or morphemes. For example, to discover the English past tense marker *-ed*, a child must first notice this morpheme in different verbs to find out that it is used for past tense.

Chiat (2001) suggests that children with DLD are impaired in their access to the details of phonological structures, especially rhythmic information, that are necessary for forming stable representations of lexical words and syntactic structures. The phonological details are 'unavailable or unstable in the child's perception, storage, and/or retrieval' (p. 124). So, this phonological theory of DLD proposes that language deficits, especially morphosyntactic deficits, are caused by a phonological impairment, leading to unstable lexical or syntactic representations. This theory thus predicts that children with DLD have difficulty in verb inflection, which is also found by, among others, de Jong (1999) and Spoelman and Bol (2012), see Section 2.3.3. The hypothesis by Marshall et al. (2003) that children with DLD have unstable and underspecified representations of syllables also fits this theory.

In the model by Terband et al. (2016), this deficit of children with DLD is located in the phonological decoding module, because Chiat (2001) suggests that children with DLD have difficulty in detecting and forming stable phonological representations. The output of the phonological decoding module is impaired, and, therefore, the grammatical decoding module receives impaired input as well. This causes difficulty in detecting the grammatical structures of words in the speech input. Furthermore, stable representations of words are needed to form stable lemmas in the mental lexicon. This would thus mean that children with DLD have unstable representations of words. Because of the problems with grammatical decoding, the lemmas in the mental lexicon neither contain stable grammatical structures. This, in turn, affects grammatical encoding, because these words and their structures are needed to build a sentence structure. The words that are selected by the grammatical encoding module, are the input for phonological encoding. However, because of its impaired input and because of the unstable representations in the mental lexicon, difficulty in selecting the correct sounds and in ordering them are predicted as well. This model thus shows that an impairment in phonological decoding can indeed lead to grammatical and phonological errors in the perception and production of sentences. Furthermore, using this model, Chiat's theory can also explain the positive effect of phonological intervention on morphosyntactic performance that was found by Tyler and Sandoval (1994). However, this theory would not predict that a morphosyntactic intervention could lead to better phonological performance, as was found by Tyler et al. (2002).

Joanisse and Seidenberg (1998) propose that the grammatical deficit of children with DLD is caused by a deficit in their auditory processing. According to them, a perceptual deficit leads to phonological difficulties, because one must perceive all sounds in order to build correct phonological representations. This, in turn, leads to problems in morphology and syntax. This auditory deficit has the greatest effect on less perceptually salient morpho-syntactic elements, such as tense and agreement marking. Agreement marking errors were indeed found by de Jong (1999) and Spoelman and Bol (2012). However, this theory cannot explain why Rice et al. (1999) found that children with DLD are sensitive to incorrect subject-verb agreements.

According to Joanisse and Seidenberg (2003), poor phonological abilities can also lead to difficulties in sentence comprehension, because sentences are stored in a phonological form in working memory during sentence processing. Because of their phonological impairment, children with SLI have less working memory left for syntactic processing, which leads to poorer syntactic comprehension. To test this potential link between speech perception, phonology, and syntactic comprehension, Joanisse and Seidenberg performed two connectionist simulation models. One model simulated typical development, whereas the other simulated impaired language development. The models were trained to learn the binding between pronouns and reflexives to their antecedents. The phonological input in the impaired model contained noise, reflecting a speech processing deficit, which made it more difficult for the model to develop correct phonological representations. The results indicated that both models were able to detect grammatical and ungrammatical sentences, although the impaired model did not learn the binding rules as well as the unimpaired model. Furthermore, the authors found that the impaired model performed more poorly in resolving pronouns and reflexives. However, in sentences in which the context could be used to know the antecedent of the pronoun (for instance, using gender information in *She saw him in the mirror*), the impaired model performed well. Since these results are consistent with behavioural data of children with DLD, the results thus suggest that an auditory processing deficit can lead to syntactic impairments.

In the model by Terband et al. (2016), the deficit proposed by Joanisse and Seidenberg (1998) lies in the auditory processing and memory module. Because phonological decoding uses the output of the auditory processing module, it is more difficult to form stable representations of the words and morphemes in incoming speech. Hence, this can lead to impairments in the grammatical encoding, grammatical decoding, phonological decoding, and the mental lexicon modules. An auditory processing deficit can, thus, lead to difficulties in phonological and syntactic abilities of children with DLD, leading to production as well as comprehension errors. Like the phonological deficit by Chiat (2001), this theory can explain the positive cross-domain effects of a phonological intervention on morphosyntactic performance (Tyler & Sandoval, 1994), but not the positive effects of a morphosyntactic intervention on phonological performance (Tyler et al., 2002).

2.5.3 Grammatical deficit theories

A grammatical explanation for DLD is the Extended Optional Infinitive hypothesis by Rice, Wexler and Cleave (1996). They point out that all TD children go through an optional infinitive stage, as was mentioned in Section 2.2.4. In this stage, children sometimes produce sentences containing a correct finite verb, but they also produce incorrect infinite verbs. The Extended Optional Infinitive (EOI) hypothesis holds that children with DLD go through the same optional infinitive stage, but they stay in this stage for a longer period of time. This means that children with DLD allow both sentences with finite and infinite verbs, resulting in errors in tense and agreement. Rice and colleagues found, indeed, that children with DLD produce fewer finite lexical verbs compared to TD children with a similar mean length of utterance (MLU), but they do use the correct forms of the auxiliaries 'be' and 'do'. They explain this finding by suggesting that these auxiliaries do not carry other meaning than tense and agreement features. This shows, according to the authors, that children with DLD do have some knowledge of tense and subject-verb agreement, but they do not know that it is obligatory.

In the speech production and perception model by Terband et al. (2016), the grammatical deficit proposed by Rice et al. (1996) is located in the grammatical encoding module. They suggest, however, that this grammatical deficit does not influence neighbouring processes, because the deficit regards only grammatical encoding. Therefore, this theory cannot explain why children with DLD also show difficulties in other domains than syntax, such as phonology. Furthermore, it cannot explain the interactions found between syntactic and phonological abilities of children with DLD, and the positive cross-domain effects found by the described intervention studies.

2.5.4 Implicit learning deficit hypotheses

Another potential explanation for DLD is that it is caused by an implicit learning deficit. Ullman and Pierpont (2005) suggested that children with DLD have a procedural learning deficit, which is known as the Procedural Deficit Hypothesis (PDH). Ullman and Pierpont based their hypothesis on abnormalities in brain structures, especially those involved in procedural learning, in children with DLD. These abnormalities lead to implicit learning difficulties, resulting in linguistic as well as non-linguistic problems. The procedural memory system is used for implicitly learning patterns and using 'rule-governed computations', and, therefore, plays an important role in the acquisition of grammatical structures, including syntactic, morphological, and phonological structures (Ullman & Pierpont, 2005). For learning, storing, and retrieving facts and events, the declarative memory system is used. Declarative learning is, according to Ullman and Pierpont, particularly involved in learning the meaning of words. So, they organized the learning of grammar and the learning of word meanings into two learning systems; procedural learning and declarative learning respectively. This would suggest that children with DLD have a deficit in learning grammatical rules, but not in vocabulary learning. It is important to note, however, that they can still have difficulty in learning word forms (Evans, Saffran & Robe-Torres, 2009).

A type of implicit learning that is particularly important in language acquisition is statistical learning (e.g. Erickson & Thiessen, 2015; Romberg & Saffran, 2010; Wijnen, 2013). Statistical learning is the ability to detect structures and patterns in input, based on distributional properties of items and the distribution of the co-occurrence of items (Romberg & Saffran, 2010). Research showed that statistical learning can be used in phoneme categorization (Maye, Werker & Gerken, 2002), word segmentation (Saffran et al., 1996), word-referent association (Graf Estes, Evans, Alibali & Saffran, 2007), and grammatical categorization (Mintz, 2003). These processes are part of, or involved in phonology and/or syntax, and it is thus likely that the acquisition of phonological and syntactic structures rely both on a statistical learning mechanism (Wijnen, 2013).

In a meta-analysis of statistical learning in the auditory domain in individuals with and without DLD by Lammertink, Boersma, Wijnen, and Rispens (2017), it was found that individuals with DLD have significantly poorer statistical learning skills than TD individuals. Furthermore, they found no difference between statistical learning abilities in grammar learning studies and word segmentation studies. However, Lammertink and colleagues also pointed out that this null-result could have been caused by 'their relatively small number of studies in their sample' (p. 3483).

In the model by Terband et al. (2016), an implicit learning deficit cannot be placed in one specific module. Instead, it plays a role in the development of grammatical and phonological encoding and decoding processes, because all these processes make use of rules, patterns, and structures. So, if children have an impairment in their procedural memory, the development of all these linguistic processes is affected. Implicit learning theories could therefore explain the phonological as well as the syntactic difficulties found in children with DLD. Additionally, these theories predict that the difficulties in phonology and syntax are related, because they are both caused by the same underlying deficit. Different hypotheses can be formulated about cross-domain effects of intervention studies. On the one hand, it could be predicted that an intervention in syntax or phonology leads to positive effects in the other domain as well, because the intervention might lead to improvement in their statistical learning skills, which may result in better performance in both domains. This would be in line with the findings by Tyler et al. (2002) and Tyler and Sandoval (1994). On the other hand, it is possible that children with DLD need more input to detect patterns and structures than TD children. Therefore, implicit learning theories would predict that a phonological intervention does not lead to improvement in syntax, because the extra input that the children receive includes (almost) only phonological structures at the word level, and thus no syntactic structures. This would be supported by the findings by Feehan et al. (2015) and Tyler et al. (2002). However, a syntactic intervention could lead to positive effects on the phonological performance of children with DLD, because syntactic input always includes words that consist of syllables and sounds, and thus include phonological structures as well. This would be supported by the findings of Tyler et al. (2002), but contradicted by the findings of Fey et al. (1994).

2.5.5 Summary

The different theories on DLD make different predictions about potential relations in DLD. The Bucket theory predicts that better performance in the phonological or syntactic domain is related to poorer or stagnated performance in the syntactic or phonological domain respectively. Cascading theories locate the cause of DLD in different, specific, modules involved in speech production and perception. They predict relations between phonological and syntactic performance of children with DLD, because a deficit in one (phonological) module leads to impairments in subsequent (syntactic) modules. The grammatical theory only predicts difficulties in syntax, but not in phonology. Therefore, it does not predict relations between phonological and syntactic performance of children with DLD. Finally, implicit learning theories suggest that the language deficits of children with DLD are caused by an underlying impairment in detecting and learning structures. Because both phonology and syntax rely on structures, these theories predict difficulties in both domains to be related.

Some predictions are in line with the difficulties of children with DLD found by studies that were discussed in the previous sections. However, none of the theories can account for all results found by studies that examined interactions between phonological and syntactic difficulties. Because the theories make different predictions about the analyses conducted in the current study, the results can be used to differentiate the theories from each other.

3. Current study

In previous sections, potential relations between phonological and syntactic abilities of children with and without DLD were described. The most obvious similarity between phonological and syntactic development is that both require detecting and acquiring patterns and structures; either of sounds and word forms, or of sentences. In children with DLD, deficits in phonology and syntax often co-occur (Fey et al. 1994), and several relations across these domains are found. For instance, it is found that phonological properties of words or morphemes play a role in the syntactic production of verbs in children with DLD, for instance in subject-verb agreement (Blom et al., 2014; Rispens & Been, 2007), and in past tense inflection (Leonard et al., 2007). Additionally, syntactic impairments can affect phonological skills (Gallon et al., 2007). These studies seem to suggest that the phonological and syntactic abilities of children with DLD are associated in top-down (syntactic impairments affect phonological performance) as well as bottom-up (phonological impairments affect syntactic performance) manners. However, studies that examined cross-domain effects of interventions found mixed results. Some studies did not find cross-domain effects (Feehan et al., 2015; Fey et al., 1994), while other studies did find positive cross-domain effects (Tyler et al., 2002; Tyler & Sandoval, 1994). These latter studies differed in the direction of the effects they found; Tyler et al. found positive effects of a syntactic intervention on phonological performance, but not in the opposite direction, while Tyler and Sandoval found positive effects of a phonological intervention on syntactic performance, but not in the opposite direction. It is far from clear how the syntactic and phonological abilities of children with DLD are related. Additionally, most studies were about expressive phonological and syntactic skills, so relations between receptive abilities are not yet fully understood either. The aim of the current study is to explore the relation between expressive and receptive phonological and syntactic abilities of toddlers with DLD. This study examines these relations at concurrent time points, and between these time points to see whether potential improvements in these domains are associated. In other words, this study examines concurrent and longitudinal relations in phonological and syntactic development.

Based on the language processing model by Terband et al. (2016), it is argued that even if the deficit is located in one process, it can also affect other processes. This effect is also hypothesized by cascading theories on DLD (e.g. Chiat, 2001; Joanisse & Seidenberg, 1998), because a problem in one process results in deficient output, which is in turn also deficient input for the next process. These theories predict, therefore, that children with DLD have difficulties in phonology as well as in syntax. The same can be said about hypotheses that relate DLD to a deficit in implicit learning (e.g. Evans et al., 2009; Ullman & Pierpont, 2005), although in this case the problem is not located in one specific process, but rather in an underlying process that is used for detecting and learning patterns, structures, and rules. A deficit in this mechanism affects both phonology and syntax, because these domains both involve patterns and structures. The Bucket theory (Crystal, 1987), on the other hand, predicts a trade-off between different linguistic domains; better performance in phonology could result in a decrease or stagnation in syntax, and vice versa. So, this theory predicts that children with DLD do not improve in multiple linguistic domains at the same time, which is thus in direct opposition with the model by Terband and colleagues (2016). Finally, the grammatical deficit theory by Rice et al. (1996) only predicts difficulties in grammatical language processes, and therefore no links between phonological and syntactic impairments. To sum up, all these different theories, except the purely grammatical theory by Rice et al., predict relations between the phonological and syntactic abilities of children with DLD. However, the previous sections also made clear that none of the theories can account for all results found by studies that examined interactions between phonological and syntactic difficulties. Moreover, the findings of these studies, especially the findings of intervention studies, are inconsistent. Therefore, it is not clear if and how the phonological and grammatical difficulties of children with DLD are related, and which theory could explain potential interactions best.

The main research question of the present study is whether, and if so how, expressive and receptive phonological and syntactic abilities of toddlers with DLD are related. As expressive phonological development index, the PMLU (Phonological Mean Length of Utterance) is used, which provides an indication of the phonological length and correctness of utterances produced by a child. As receptive phonological development index, scores on a perceptual minimal pair task (MPT) are used, which indicate the perceptual auditory discrimination skills of a child. As expressive and receptive syntactic indexes, scores on the Schlichting test are used. This test is designed to monitor the syntactic development of young Dutch children (Schlichting & Lutje Spelberg, 2003). The specific research questions are:

1. Are the PMLU and score on the MPT of toddlers with DLD related to their syntactic comprehension and production scores on the Schlichting test at measurement 1?
2. Are the PMLU and score on the MPT of toddlers with DLD related to their syntactic comprehension and production scores on the Schlichting test at measurement 2 (five months after measurement 1)?
3. Do toddlers with DLD improve in their phonological and syntactic abilities, and if so, are these improvements related?
4. Do toddlers diagnosed with an inconsistent deviant phonological disorder and toddlers diagnosed with a delayed or consistent phonological disorder differ in their scores on syntactic comprehension and production?

The first two questions examine whether the phonological production abilities of toddlers with DLD are related to their syntactic abilities at concurrent time points. The third research question pertains to a longitudinal relation between phonology and syntax; it is examined whether toddlers who improve in their phonological performance also improve in their syntactic performance, and vice versa. Finally, the fourth question is about how different phonological diagnoses could relate to differences in syntactic development. This is interesting to consider, because it is suggested that children with an inconsistent phonological diagnosis do not have a phonological rule system, while children with a consistent or delayed phonological diagnoses do have such a system, although this is an incorrect or immature system. This last question thus explores how different phonological systems could affect syntactic comprehension and production.

Based on the different theories on DLD, different predictions can be formulated. Regarding the first two research questions, the Bucket theory predicts that toddlers who have a higher PMLU/ MPT score, score lower on the Schlichting test, and vice versa. The cascading theories predict that lower PMLUs/MPT scores are related to lower scores on the Schlichting test, and higher PMLUs/MPT scores are related to higher scores on the Schlichting test. Furthermore, these theories predict higher correlations within the expressive domain (i.e. PMLU and syntactic production) and within the receptive domain (i.e. MPT and syntactic comprehension) than across these domains, because the expressive skills are part of the process of speech production, while the receptive skills are part of the process of speech perception. Finally, the implicit learning theories hypothesize that children with DLD perform poorly in both phonology and syntax. So, these theories predict low PMLUs and MPT scores and low scores on the Schlichting test for all toddlers. However, children can differ in the severity of their statistical learning deficit, so these theories also predict that higher PMLUs/MPT scores are related to lower scores on the Schlichting test. Based on purely grammatical theories, only low scores on the Schlichting test could be predicted, but no interactions between phonology and syntax. However, because several studies found phonological difficulties in children with DLD (e.g. Marshall et al., 2003; Rescorla & Ratner, 1996), this is not a likely result.

As for the third research question, the Bucket theory predicts that children who improve in their phonological or syntactic abilities, show no improvement, or perhaps even a decrease, in their syntactic or phonological abilities respectively. Since the cascading theories posit that the developments of different abilities depend on each other and because they locate the deficit of children with DLD within their receptive phonological abilities, these theories predict that improvement in this latter domain would lead to improvement in expressive phonological abilities and receptive and expressive syntactic abilities as well. Because syntactic abilities cannot improve without improvement in phonological abilities, the theories also predict that children who improve in their syntactic abilities must also improve in their phonological abilities. In other words, cascading theories predict that children who improve in their phonological abilities, also improve in their syntactic abilities, and children who do not improve in their phonological abilities, neither improve in their syntactic abilities, and vice versa. Moreover, because the deficit is located in receptive phonological skills, cascading theories hypothesize that receptive phonological performance could be used to predict syntactic performance later on in development, but syntactic performance cannot predict receptive phonological performance later on in development. It is not entirely clear what implicit learning theories predict for the relation between the improvements in syntax and phonology, but they could predict the same as cascading theories; children who improve in phonology also improve in syntax, and vice versa. These theories could also make the prediction that syntactic improvement could result in phonological improvement. Because sounds and syllables are necessarily part of words and sentences, syntax can be seen as a higher linguistic level (Norris & Hoffman, 1990). From a top-down approach, syntactic improvement could therefore include improvement in lower linguistic domains, such as phonology. The grammatical theory of DLD does not predict any relations for the improvement in these domains.

Finally, if phonological and syntactic abilities are related, it could be the case that different phonological disorders affect syntactic abilities in divergent ways. The last research question addresses this issue. Children with inconsistent deviant phonological disorders make inconsistent errors, indicating that they do not have a phonological system, whereas children with a consistent disorder do have a system, although their system is deviant from a typically developing phonological system. Implicit learning theories predict that children who do not have a phonological system have more difficulty in detecting structures and building rules than children who do have a phonological system. Therefore, children with an inconsistent phonological diagnosis could also score lower on syntactic tests, because they are likely to have more difficulty in building a syntactic rule system as well. If children with an inconsistent phonological disorder score lower on the Schlichting test compared to children with a consistent phonological disorder, this would provide a further indication that phonological difficulties are related to syntactic difficulties of toddlers with DLD.

The hypotheses formulated by the four theories on the cause of DLD are summarized in Table 1. Because all theories make different predictions about the research questions, the results of the current study could be used to compare these theories.

Table 1. Summary of hypotheses made by the different theories on DLD. - indicates predicted negative correlations, 0 indicates no predicted correlations, + indicates predicted positive correlations and predicted differences. If no hypothesis can be formulated, the square is left blanc.

	Correlations concurrent time points	Correlations improvement	Differences between abilities in the receptive and expressive domains	Receptive phonological abilities can predict syntactic abilities, but syntactic abilities cannot predict receptive phonological abilities	Differences in syntactic performance between toddlers with inconsistent and consistent phonological diagnoses
Bucket theory	-	-			
Cascading theories	+	+	+	+	
Grammatical theory	0	0			
Implicit learning theories	+	+			+

4. Method

4.1 Participants

The participants were 45 toddlers aged between 2;4 and 4;3 (M = 3;6). These toddlers participated in a phonological intervention study conducted by the *Royal Dutch Auris Group* (*Auris*), and were therefore selected on their phonological difficulties. The toddlers went to specialized treatment groups for children with suspected DLD, where the focus lies on improving their language abilities, and most toddlers received individual language and/or speech therapy once a week, next to language and speech activities in the group. The participants of this study were only those toddlers who took part in the phonological intervention and for whom scores on the Schlichting test were available.

The native language of most participants was Dutch, but there were also bilingual participants who, besides Dutch, had another native language. The languages of the children who participated in measurement 1 and 2 can be found in Table 2. This was all available information about the bilingual children.

Table 2. Native languages of participants in measurement 1 and 2.

Native language	Measurement 1	Measurement 2
Dutch	35	20
Arabic	5	2
Mandarin-Chinese	2	1
Turkish	1	1
Armenian	1	1
Kurdish	1	0

4.2 Data collection

The data was collected by the *Royal Dutch Auris Group*. *Auris'* researchers conducted a phonological intervention study, in which they examined the phonological production and perception abilities of toddlers at different time points in order to assess the effect of an added group intervention. For the current study, data was used of their first (baseline) measurement, which took place before the intervention, and of a post-intervention measurement approximately five months later (M = 5 months, SD = 1.4 weeks).

The Schlichting test was administered approximately once in five months time (comprehension part: M = 5 months and 3 weeks, SD = 1 week, production part: M = 5 months and 2 weeks, SD = 2 weeks) in order to monitor children's syntactic development. The scores on the Schlichting test of the participating children were retrieved from *BergOp*, a digital database used by *Auris* treatment groups to store information of children in order to monitor their development. Children of whom no Schlichting scores could be found in *BergOp* were excluded from the current study.

The syntactic and phonological data per child were collected within a range of one year, meaning that the second, either phonological or syntactic, measurement took place within a year after the first, either phonological or syntactic, measurement. Potential time points are visualized in Figure 3. Each block represents a period of five months, and tests are conducted at the beginning and end of each block. Thus, if the Schlichting test of a specific toddler was administered at time point 1 (S1), the second Schlichting test was administered approximately five months later (S2), and the second phonological measurement (P2) took place within a year after the first Schlichting test (S1). (1) in Figure 3 is an example in which the phonology and syntax blocks overlap, so the first phonological (P1) and syntactic (S1) measurements are close together, and the second phonological (P2) and syntactic (S2) measurements are close together. (2) is a visualization of a child in which the first phonological measurement (P1) was administered before the second syntactic measurement (S2), and (3) is a visualization of a child in which the syntactic tests (S1 and S2) are administered before the first phonological test (P1).

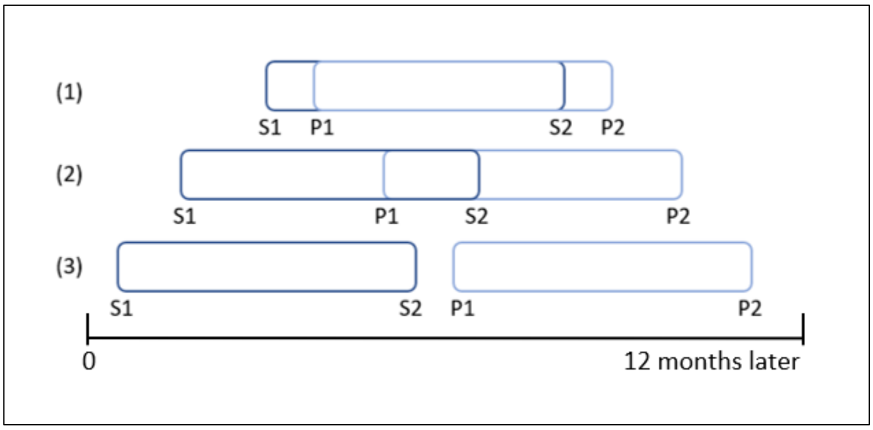

Figure 3. Three visualisations of time points at which the phonological and syntactic tests could be conducted. The dark blue boxes represent syntax, while the light blue boxes represent phonology. The tests were conducted at the beginning and end of each box. S1 stands for the first syntactic measurement, S2 for the second syntactic measurement, P1 for the first phonological measurement, and P2 for the second phonological measurement.

The number of weeks between the first phonological and syntactic measurements ranged between 1 and 20 weeks, with a mean of 8 weeks (SD = 6 weeks). The number of weeks between the second phonological and syntactic measurement ranged between 1 and 25 weeks, with a mean of 9 weeks (SD = 5 weeks). The current study did not examine the effect of the phonological intervention on syntactic skills, because the Schlichting test was not always conducted close to the phonological measurements, but only examines the improvement per child in both language domains over similar periods of time.

4.3 Outcome measures

The aim of the phonological intervention study conducted by *Auris'* researchers was that children would learn to notice differences and similarities between sounds, and that way (re)organize and expand their phonological system. The intervention consisted of fifteen sound training sessions distributed over two months, focusing on five different consonants or consonant clusters: /n-/, /st-/, /-k/, /l-/, and /-f/. The children were tested six times by speech pathologists over a period of six months, of which the first and fifth measurements were used in the current study. At each measurement time, different tests were conducted, including the Metaphon screening and the *Nederlands Articulatie Onderzoek*

Verwervingsvolgorde (NAO_VW, 'Dutch Articulation Assessment - Order of Acquisition'). At the first and fifth measurement times, a perceptual minimal pair test (MPT) was conducted as well.

Each measurement was filmed and lasted approximately twenty minutes. The Metaphon screening and NAO_VW are both picture naming tasks, which consist of 42 and 39 target words respectively. In the MPT, three pictures were presented and named by the speech pathologist first, subsequently the pathologist asked the child to point at one of the pictures, and the child had to point at the picture matching the word the speech pathologist asked for. One of the pictures was a picture of a phonological distractor that differed only in one sound from the target word (i.e. a minimal pair), for example *taart* ("pie") and *staart* ("tail"). The third picture was a non-related (both phonologically and semantically) distractor. This task consisted of two practise items and fifteen test items, and was used to test auditory discrimination abilities, and thus, phonological perception. The produced words in the Metaphon screening and NAO_VW were transcribed by a speech pathologist. For a subsample of the children (10%), a second speech pathologist made transcriptions as well. These transcriptions were compared with the transcriptions of the first transcriber, in order to check the reliability of the transcriptions. The intraclass correlation coefficient (ICC) was 0.803, indicating good reliability of the transcriptions (Koo & Li, 2016). Based on the transcriptions, the PMLU, the phonological production index, was calculated. This was done as follows: one point was counted for each consonant and vowel that occurred in the produced word, and an additional point was added for each correctly produced consonant. For example, the if the word *taart* was produced correctly as [ta:rt], the PMLU was 7 (four phonemes + three correctly produced consonants), while the PMLU was 5 if the word was produced as [ta:t] (three phonemes + two correctly produced consonants). The final PMLU score was the mean score over all produced words.

The Schlichting test consists of several parts, including parts testing syntactic comprehension (Schlichting & Spelberg, 2010a) and production (Schlichting & Spelberg, 2010b). The Schlichting test can be used to monitor the syntactic development of young Dutch children (Schlichting & Lutje Spelberg, 2003). In the syntactic comprehension items, the child is, for instance, asked to point to something, or to carry out a simple assignment. For example, in one item, the experimenter provides a toy monkey and house to the child, and, after checking whether the child knows the words ‘monkey’ and ‘house’, she asks the child to put the monkey on top of the house. An item is scored as correct if the child carries out the target assignment. In the syntactic production items, functional imitation is used to elicit responses of children, which means that an imitation has a communicative purpose. Examples of utterances the experimenter tries to elicit are *die ook* (‘that one(s) too’) and *ook een vis* (‘also a fish’). Items are only scored as being correct if the child produces certain target words. All items are scored by a speech and language pathologist. The final raw score is the sum of all correct responses per subtest, and there are, thus, separate scores for the syntactic comprehension and production part. These raw scores were used in the current study to index the syntactic comprehension and syntactic production skills of the participants. Standardized scores were not used, because these scores index improvement relative to language development of TD toddlers, while the current study is interested in improvement relative to a previous measurement.

4.4 Analysis

The design of the study was a within-subjects design, and children were tested at different time points with the syntactic and phonological tests described above. In order to see whether phonological production and perception were related to syntactic production and comprehension within concurrent time points (i.e. measurement 1 and measurement 2), correlation analyses were conducted between the PMLU and the MPT on the one hand, and syntactic production and comprehension scores on the Schlichting test on the other hand. Pearson’s correlations were used when the data was normally distributed and when the plotted data showed a linear relationship between the two factors. Otherwise, Spearman’s correlations were conducted. Scatterplots were made using the *ggplot2* package (Wickham, 2016) in R (R Core Team, 2016).

SPSS (version 23) was used to conduct a linear mixed effects analysis to examine the relation between the improvements in phonological and syntactic abilities. Because each child was tested four times (i.e. two times on their phonological abilities, and two times on their syntactic abilities), a repeated factor was added to the model to control for the cohesion within subjects. This factor was a combination of the factors measurement point (1 and 2) and language domain (phonology and syntax), and therefore consisted of four levels. This factor will be referred to as MLD (Measurement and Language Domain). MLD was also added as fixed factor to the model, and the dependent factor was the score on each test (i.e. expressive phonological and syntactic scores and receptive phonological and syntactic scores). The repeated covariance type was set to Unstructured (with Correlation Metric) in order to see how the different levels of MLD were correlated with each other. To test whether the children on average improved within one language domain, estimated marginal means were calculated and pair wise comparisons, with Bonferroni corrections, were performed between the first and second measurements. Additionally, the unstructured repeated covariance type was used to see whether the first and second measurements were correlated within phonology and syntax. A positive correlation between the two time points would mean that children who had a high score on the first measurement, also had a high score on the second measurement, and vice versa. Finally, correlations between different language domains and different measurements were calculated to examine whether a score in either phonology or syntax on the first measurement could be used to predict the score on the second measurement in the other domain. If children improved in both domains, and if a first measurement in one language domain could be used to predict the second measurement in the other domain, this would suggest that the improvements in both domains are related.

Finally, it was examined whether children who were classified by *Auris'* speech and language pathologists as showing consistent phonological error patterns differed from children who were classified as showing inconsistent phonological error patterns in how much they improved in the syntactic subdomains. The consistent group consisted of children with a phonological delay and children with a consistent deviant phonological disorder (n = 8). The inconsistent group consisted of children with an inconsistent deviant phonological disorder (n = 8). This analysis was only assessed on toddlers with one of these three diagnoses (phonological delay, consistent or inconsistent deviant phonological disorder). Toddlers diagnosed with another phonological diagnosis (n = 9) were not included. Because the number of participants in each group was so small, no quantitative analyses were conducted on this data. Instead, the mean improvements in syntactic comprehension and production were described and compared between the two groups. So, this can be seen as an explorative qualitative analysis, which could merely give an indication of similarities or differences between the two diagnostic groups in their syntactic development.

5. Results

5.1 Measurement 1

For measurement 1, phonological production (PMLU) and syntactic comprehension and production data of 45 toddlers, aged between 2;4 and 4;1 (M = 3;4, SD = 5 months), were available. For two of these toddlers, no phonological perception scores (MPT) were available, so analyses that included the MPT were conducted on data of 43 toddlers, with the same age range and mean age as the group of 45 toddlers.

Figure 4 shows the correlations between the scores on the syntactic comprehension and production parts of the Schlichting test and the PMLU and MPT scores at measurement 1. As can be seen in the figure, a significant positive correlation was found between PMLU (M = 4.18, SD = 0.79) and syntactic production (M = 4.40, SD = 2.69), $r(44) = 0.67$, $p < 0.01$, but not between PMLU and syntactic comprehension, $r(44) = 0.29$, $p = 0.052$, although this correlation is close to significant. Another significant positive correlation was found between the score on the MPT (M = 9.84, SD = 3.56) and syntactic comprehension (M = 21.35, SD = 11.73)[1], $r(42) = 0.52$, $p < 0.001$. No correlation was found between MPT and syntactic production (M = 4.49, SD = 2.72), $r(42) = 0.12$, $p = 0.43$.

[1] PMLU scores of 45 children and MPT scores of 43 children were available, so the mean scores and standard deviations of the syntactic variables slightly differ between the correlations.

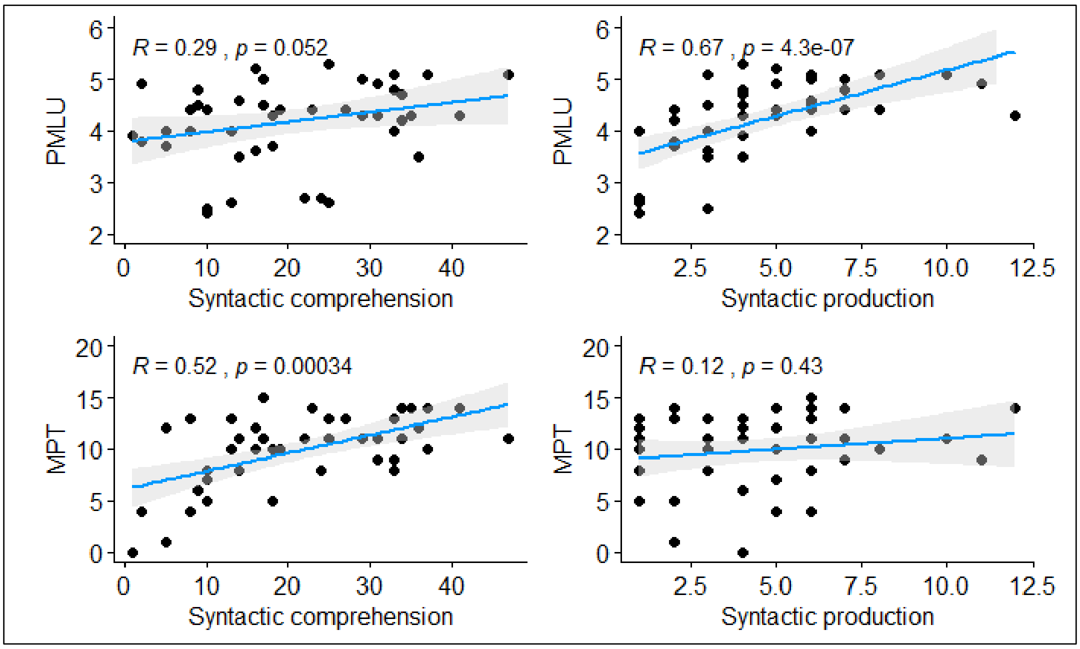

Figure 4. Correlations with 95% Confidence Intervals (CI) between the syntactic comprehension and production scores on the Schlichting test and PMLU and MPT scores at measurement 1.

5.2 Measurement 2

For measurement 2, data of 25 toddlers were available. These toddlers were aged between 3;0 and 4;3 (M = 3;8, SD = 4 months). However, of one child, no MPT score was available. Therefore, analyses that included the second MPT score were conducted on the data of 24 children, aged between 3;3 and 4;3 (M = 3;9, SD = 4 months).

Figure 5 presents the correlations between the scores on the syntactic comprehension and production parts of the Schlichting test and the PMLU and MPT scores at measurement 2. A significant positive correlation was found between PMLU (M = 4.64, SD = 0.79) and syntactic production (M = 6.76, SD = 2.51), r(24) = 0.53, $p < 0.01$, but not between PMLU and syntactic comprehension (M = 32.92, SD = 9.88), r(24) = -0.076, p = 0.72. Additionally, a significant positive correlation was found between the score on the MPT (M = 9.84, SD = 3.56) and syntactic comprehension (M = 33.08, SD = 10.06), r(23) = 0.55, $p < 0.01$. No correlation was found between MPT and syntactic production (M = 6.75, SD = 2.56), r(23) = 0.38, p = 0.065, although this correlation approaches significance.

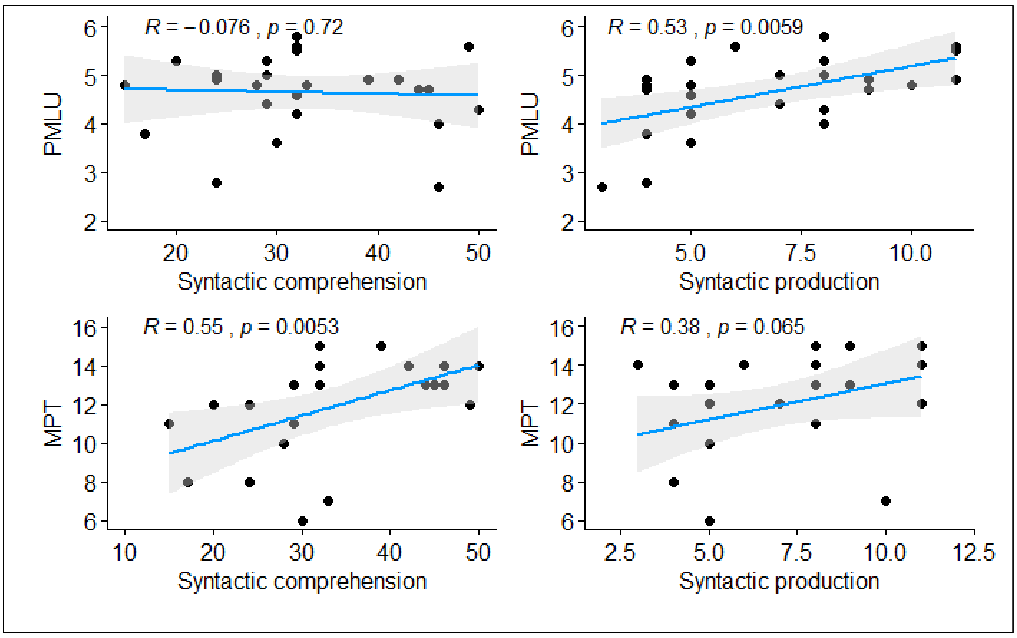

Figure 5. Correlations between the syntactic comprehension and production scores on the Schlichting test and PMLU and MPT scores at measurement 2.

In short, within both measurement points significant correlations were found between receptive phonological (MPT) and receptive syntactic (syntactic comprehension) abilities, and between expressive phonological (PMLU) and expressive syntactic (syntactic production) abilities, but not between expressive and receptive abilities, although some of these latter correlations approach significance.

5.3 Relation between phonological and syntactic improvement

The mixed effects analyses of improvement over time were only conducted within the receptive and expressive domains, in order to see whether the improvement in receptive and expressive phonological scores were related to the receptive and expressive syntactic scores respectively. As was mentioned before, these analyses were only conducted for the children of whom the phonological and syntactic data were available at both measurement points. The complete SPSS output from the expressive mixed model can be found in Appendix 1, and the output of the receptive model in Appendix 2.

5.3.1 Expressive mixed model

The expressive analysis was conducted on the scores of the same group of children as the second measurement, thus of whom the phonological production scores were available. These toddlers (n = 25) were aged between 3;0 and 4;3 (M = 3;8, SD = 4 months).

The mixed effects analysis showed that there was a significant effect of the factor MLD ($F(25, 4) = 228,67$, $p < 0.001$). The estimated marginal means of the mean PMLU and syntactic production scores at both measurements are given in Table 3. This table shows that, on average, participants improved in both domains. Pairwise comparisons, with Bonferroni corrections, of the scores at measurement 1 and 2 showed that the improvement in expressive phonological ($p < 0.001$, CI[2] = 0.37 – 0.84) as well as the progress in syntactic scores ($p < 0.001$, CI = 1.94 – 4.38) were significant.

Table 3. Estimated marginal means of the expressive phonological and syntactic scores on each measurement.

	Measurement	Estimated marginal mean	Std. Error	df	95% Confidence interval
PMLU	1	4.04	0.17	25	3.69 – 4.39
	2	4.64	0.16	25	4.32 – 4.69
Syntactic production	1	3.60	0.41	25	2.75 – 4.45
	2	6.76	0.49	25	5.75 – 7.77

The correlation calculated from the variance estimates (see Appendix 1) between the first and second phonological measurements was 0.87 ($p < 0.001$, CI = 0.74 – 0.94), indicating that most children who had a high PMLU at the first measurement, still had a high PMLU at the second measurement, and children who had a low PMLU at the first measurement, still had a low PMLU at the second measurement. Additionally, the variance of the PMLU at measurement 1 was 0.70 (SE = 0.20), and at measurement 2 0.60 (SE = 0.17). Thus, children differed less from each other in their PMLU at measurement 2 than at measurement 1. Regarding syntactic production scores, the correlation

[2] Confidence intervals for the difference between measurement 1 and 2

between the first and second measurements was 0.57 ($p < 0.001$, CI = 0.25 – 0.78), indicating that the scores were related, but not as strongly as the PMLUs at the two time points. The variance of the syntactic production score at measurement 1 was 4.24 (SE = 1.20), and at measurement 2 6.02 (SE = 1.70), indicating that children differed more from each other at the second measurement. Visualizations of the correlations between the first and second measurements are provided in Figure 6. The regression lines in these plots are, however, not corrected for the repeated factor used in the mixed effects model, thus these plots only give an impression of the data distribution.

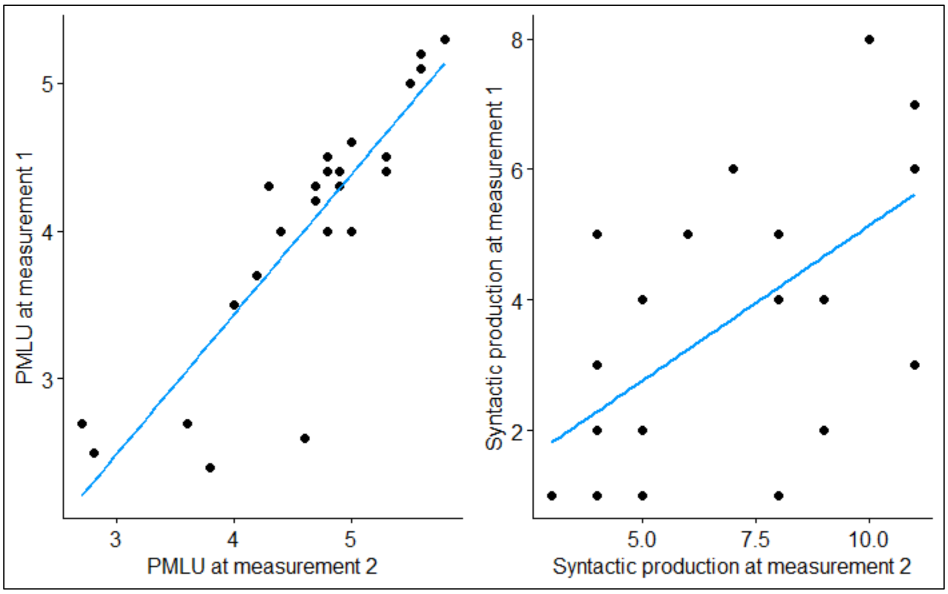

Figure 6. Scatterplots with regression lines of the first and second phonological (left) and syntactic (right) production scores.

Finally, the model calculated the correlations between the first measurement on one language domain and the second measurement on the other domain, in order to see whether the first measurement could be used to predict the second score in the other domain. The correlation between PMLU on measurement 1 and syntactic production on measurement 2 was 0.58 ($p < 0.001$, CI = 0.26 – 0.78). This implies that the PMLU on measurement 1 could be used to predict the syntactic production score on measurement 2. The correlation between syntactic production on measurement 1 and PMLU on measurement 2 was 0.40 ($p = 0.018$, CI = 0.029 – 0.67), suggesting that this syntactic production score could be used to predict PMLU at measurement 2. However, this last correlation was lower than the previous correlation, suggesting that PMLU is a better predictor for syntactic production score than the syntactic production score is for PMLU. However, due to large confidence intervals these results should be interpreted with caution. Figure 7 shows scatterplots of the relations between the first phonological/syntactic and second syntactic/phonological measurements. The regression lines in these plots are not corrected for the repeated factor MLD, thus these plots merely provide an indication of what the distributions look like.

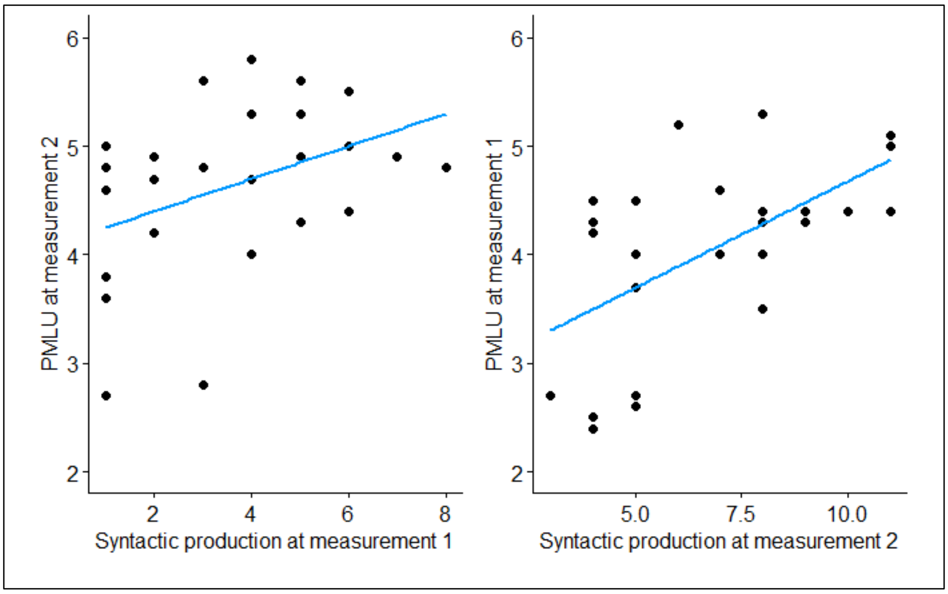

Figure 7. Scatterplots with regression line of the relations between the first syntactic and second phonological measurement (left) and between the first phonological and second syntactic measurement (right) in the expressive domain.

5.3.2 Receptive mixed model

The receptive model covered the scores of 23 children aged between 2;10 and 3;10 (M = 3;4, SD = 4 months).

For the receptive phonological and syntactic abilities, the repeated mixed effects analysis showed that there was a significant effect of the factor MLD on the test scores ($F(23.28, 4) = 144.35$, $p < 0.001$). Table 4 shows the estimated marginal means of the PMLU and syntactic production score for both measurements. Like the expressive abilities, the participants as a group improved in both language domains. Pairwise comparisons, with Bonferroni corrections, showed that the improvement in MPT score was significant (p = 0.025, CI = 0.17 – 3.45), and so was the improvement in syntactic comprehension (p < 0.001, CI = 10.26 – 16.31).

Table 4. Estimated marginal means of the receptive phonological and syntactic scores on each measurement.

	Measurement	Estimated marginal mean	Std. Error	df	95% Confidence interval
MPT	1	9.96	0.608	24.245	8.70 – 11.21
	2	11.77	0.529	25	10.68 – 12.86
Syntactic comprehension	1	19.64	1.843	24.316	15.85 – 23.44
	2	32.92	1.937	25	28.93 – 36.91

The correlation between the first and second phonological measurement was 0.53 (p = 0.001, CI = 0.16 – 0.77). Thus, there was a significant correlation, although the correlation was not very strong (Taylor, 1990). The variance at measurement 1 was 9.09 (SE = 2.64), and at measurement 2 6.82 (SE = 1.97). Hence, children differed less from each other at the second measurement point. The correlation between the first and second syntactic measurement was 0.84 (p < 0.001, CI = 0.69 – 0.93), indicating that children who scored high on the first measurement, had also high scores on the second measurement. The variance at measurement 1 was 84.87 (SE = 24.00), and at measurement 2 93.75 (SE = 26.52). This indicates that children differed less from each other at measurement 1. Visualizations of the correlations between the first and second measurements are provided in Figure 8. The regression lines in these plots are, again, not corrected for the repeated factor used in the mixed effects model, thus these plots only give an impression of the data distribution.

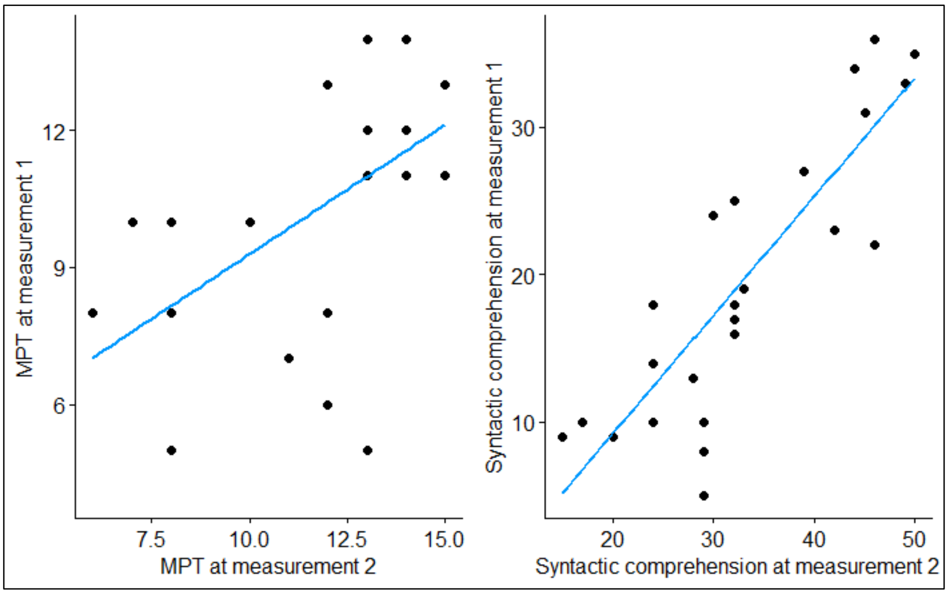

Figure 8. Scatterplots with regression lines of the first and second phonological (left) and syntactic (right) receptive scores.

Finally, the repeated mixed effects model showed that the correlation between the first phonological measurement and the second syntactic measurement was 0.71 ($p < 0.001$, CI = 0.45 – 0.86). This significant correlation indicates that the MPT score on measurement 1 could be used to predict the syntactic comprehension score on measurement 2. The correlation between the first syntactic comprehension score and the second MPT score was 0.35 ($p = 0.051$, CI = -0.04 – 0.65), which was almost significant. Because it approaches significance, this correlation suggests that the first syntactic comprehension score could be used as a predictor of the second MPT score, although this correlation is not very strong. Figure 9 shows scatterplots of the relations between the first phonological/syntactic and second syntactic/phonological measurement points. The regression lines in these plots are, again, not corrected for the repeated MLD factor.

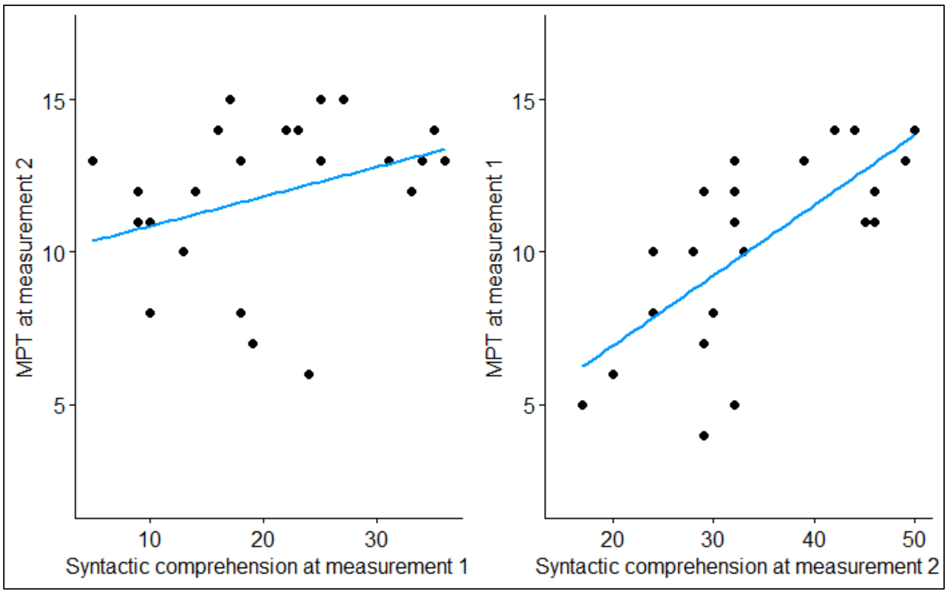

Figure 9. Scatterplots with regression line of the relations between the first syntactic and second phonological measurement (left) and between the first phonological and second syntactic measurement (right) in the receptive domain.

To sum up, because the results meet two premises: (1) children improved, on average, in each domain, and (2) the first phonological measurements could be used to predict the second syntactic measurements, and the first syntactic measurements could, in part, be used to predict the second phonological measurements, these results demonstrate that the improvements in expressive phonology and expressive syntax, and in receptive phonology and receptive syntax are positively related in toddlers with DLD.

5.4 Exploration of effects of phonological diagnoses on syntactic performance

The repeated mixed effects analyses showed that the participants improved on average in both their receptive and expressive phonological and syntactic scores. Additionally, it was demonstrated that the phonological measurements could be used to predict the syntactic measurements. The not very high, although significant, correlation in the expressive domain indicated that there was still considerable variation between the participants. Therefore, it was examined whether children with different phonological diagnoses scored differently on the syntactic tests. One group consisted of children diagnosed with a phonological delay or with a consistent deviant phonological disorder (n = 8). The other group consisted of children diagnosed with an inconsistent deviant phonological disorder (n = 8). Because of the low number of participants in each group, only descriptive analyses were conducted here. Hence, these analyses are an exploration of potential differences between children diagnosed with a consistent phonological disorder and children diagnosed with an inconsistent phonological disorder. Therefore, only differences in means will be described, but no conclusions about these potential differences can be drawn.

Firstly, the mean PMLU was calculated per group in order to see whether one group had more severe expressive phonological impairments than the other group. The mean PMLUs for the consistent and inconsistent group did not seem to differ much from each other, as the bar plots in Figure 10 indicate, although the mean PMLU of children with an inconsistent phonological was slightly lower than the mean PMLU of children with a consistent phonological diagnosis at both measurement points.

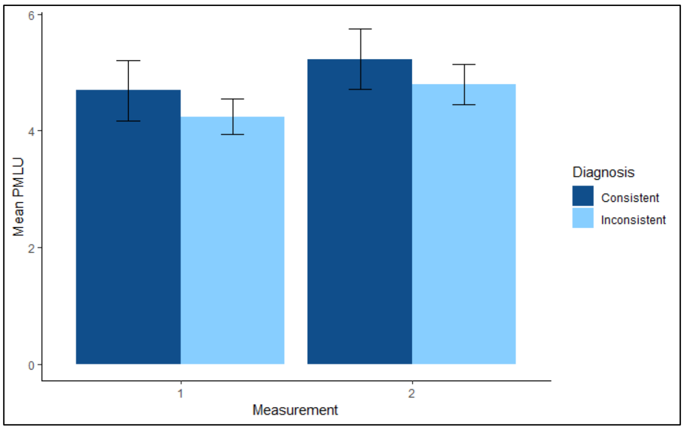

Figure 10. Mean PMLU per diagnostic group. The lines indicate the standard deviations.

Figure 11 shows the mean syntactic production scores for each diagnostic group for both measurement points. The bar plots suggest that both groups started approximately at the same level. Both groups have higher scores on measurement 2 than on measurement 1, which could indicate that both groups improved in their syntactic production. Additionally, the difference between the first and second measurement points in the consistent group seems to be larger than the difference between the first and second measurement points in the inconsistent group.

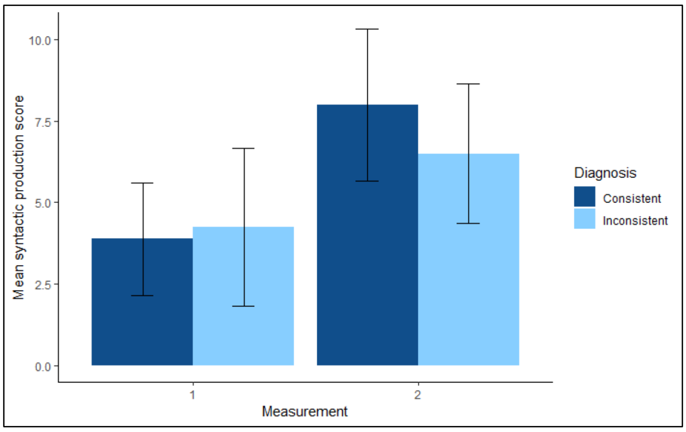

Figure 11. Mean syntactic production scores per diagnostic group. The lines indicate the standard deviations.

Regarding receptive abilities, the mean MPT score was calculated to see whether one diagnostic group had more severe receptive phonological impairments than the other diagnostic group. The bar plots in Figure 12 suggest that the group of children with a consistent phonological diagnosis had higher scores on the MPT than the group of children with an inconsistent phonological diagnosis at both measurement points.

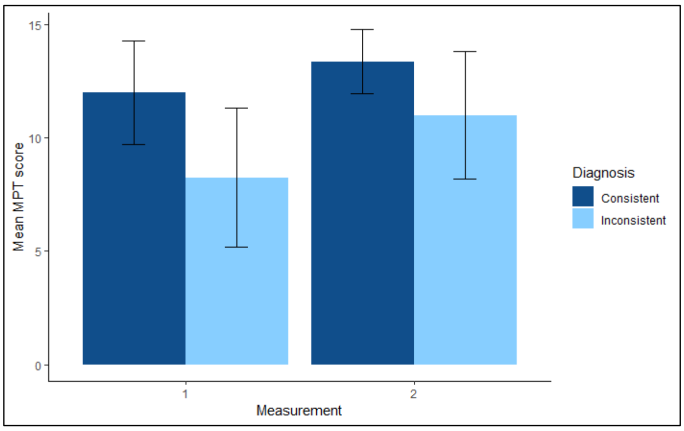

Figure 12. Mean MPT score per diagnostic group. The lines indicate the standard deviations.

Figure 13 shows the mean syntactic comprehension score per diagnostic group for each measurement point. Like the MPT scores, the mean syntactic comprehension scores seem to differ at measurement 1 as well as at measurement 2. The bars suggest that both groups improved, although the mean syntactic comprehension score of the children with an inconsistent phonological disorder seemed to be lower than the mean score of the children with a consistent phonological disorder at both measurement points. Because of the similarity with the receptive phonological scores, it could be that the differences in receptive syntactic performance were caused by differences in the severity of receptive phonological abilities.

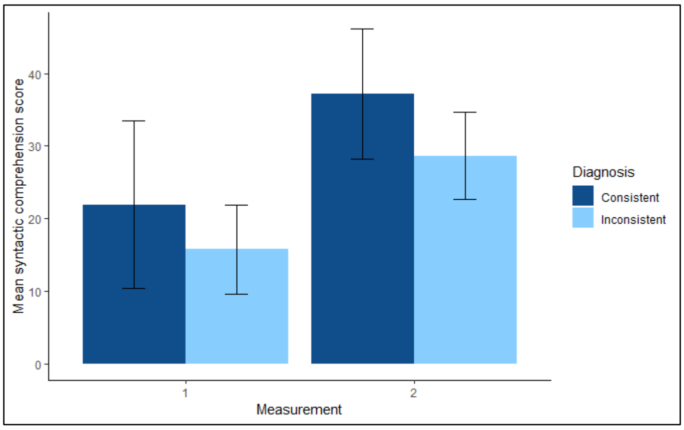

Figure 11. Mean syntactic comprehension scores per diagnostic group. The lines indicate the standard deviations.

If, and only if, the differences described by these qualitative results are actual differences, this would suggest that phonological diagnosis influences syntactic performance, especially expressive syntactic performance. This would provide further support for the existence of relations between phonological and syntactic difficulties in toddlers with DLD.

6. Discussion

6.1 Interpretation of results

The current study examined whether, and if so how, the phonological and syntactic difficulties of toddlers with DLD were related at concurrent time points, and between these time points longitudinally. The *Royal Dutch Auris Group* collected phonological expressive (PMLU) and receptive (MPT) data, and provided scores on the Schlichting test, indicating expressive and receptive syntactic skills of the same toddlers with DLD. Correlation analyses were conducted between these scores at concurrent time points. The results of these concurrent analyses showed that the phonological and syntactic scores were related within the receptive and expressive domain. The expressive phonological score (PMLU) was positively correlated with the expressive syntactic score, and the receptive phonological score (MPT) was positively correlated with the receptive syntactic score. Repeated mixed effects analyses were conducted within these domains to test whether the improvements in phonology and syntax were also correlated. These longitudinal analyses first showed that, on average, toddlers improved on each test. Thus, higher scores were obtained on the second measurement point compared to the first measurement point in both phonological and syntactic tests. Furthermore, the first expressive phonological test could predict the score on the second expressive syntactic test, and the first expressive syntactic test could predict the score on the second expressive phonological test. The same held for the receptive tests, although the correlation between the first syntactic and second phonological measurement points only approached significance. Because these scores could predict each other, and because the toddlers progressed on each test, the results indicated that improvement in phonology was related to improvement in syntax. Finally, an explorative qualitative analysis suggested that toddlers with a consistent phonological diagnosis differed from toddlers with an inconsistent phonological diagnosis in their receptive phonological skills, but not in their expressive phonological skills. Nevertheless, toddlers with a consistent phonological disorder seemed to improve more in their expressive syntactic skills and seemed to have higher receptive syntactic scores on both measurement points than toddlers with an inconsistent phonological disorder. However, because only qualitative analyses were conducted, no conclusions can be drawn from this data.

The finding that phonological and syntactic abilities of toddlers with DLD are related is in agreement with the findings by Tyler (2002), Blom et al. (2014), Leonard et al. (2007), and Gallon et al. (2007), which all demonstrated relations between phonological and syntactic processing. Furthermore, the positive effects of syntactic interventions on phonological performance (e.g. Tyler et al., 2002) and the positive effects of phonological interventions on syntactic performance (e.g. Fey et al., 1994; Tyler & Sandoval, 1994) also suggested positive correlations between phonological and syntactic development of children with DLD and are, therefore, also in agreement with the findings of the current study.

6.2 Comparison of theories on DLD

A secondary goal of this study was to compare different theories on the cause of DLD. These theories were the Bucket theory (Crystal, 1987), a grammatical theory (Rice et al., 1996), cascading theories (Chiat, 2001; Joanisse & Seidenberg, 1998), and implicit learning theories (Evans et al., 2009; Ullman & Pierpont, 2005).

The Bucket theory predicted that toddlers with higher phonological scores would perform poorer on the Schlichting test at concurrent time points (i.e. measurement 1 and 2). However, positive correlations were found between phonological and syntactic scores within both the receptive and expressive domain at measurement 1 and at measurement 2. Furthermore, this theory hypothesized that toddlers who improved in their phonological or syntactic capacities, would stagnate or decline in, respectively, their syntactic or phonological capacities. Thus, this theory did not predict the finding that children as a group improved on all four tests, and that positive correlations were found between the first phonological/syntactic test and the second syntactic/phonological test within the receptive and expressive domain. Therefore, the results do not support the Bucket theory. It should be noted, however, that the results cannot be seen as evidence against the Bucket theory either. The first phonological and syntactic measurements were not always administered at the same time points, see Section 4.2, but each child was tested at four different time points during their development; two time points for phonology and two different time points for syntax. Therefore, it is still possible that there would have been negative correlations between the syntactic and phonological performance when children were tested on both phonology and syntax at the same measurement point 1 and at the same measurement point 2. Nevertheless, because all significant correlations found in this study were positive correlations, negative correlations are unlikely.

The grammatical theory by Rice et al. (1996) predicted only difficulties in syntax for toddlers with DLD. The positive correlations that were found between phonological and syntactic abilities at concurrent time points, and between these time points, are not in line with this prediction. Therefore, the results of this study do not support this theory.

The cascading theories predicted that lower phonological scores would be correlated with lower syntactic scores, and higher phonological scores would be correlated with higher syntactic scores. This prediction is in agreement with the findings of the current study. Furthermore, these theories would predict stronger correlations within the expressive and receptive domains than across these domains. Receptive phonological and syntactic abilities are decoding processes in the model by Terband et al. (2016), and these processes play a role in speech perception. Expressive phonological and syntactic abilities, on the other hand, are part of speech production, which are the encoding processes in the model by Terband et al. Therefore, the results of the current study could be explained by cascading theories. The finding that the first receptive syntactic score could predict the second receptive phonological score, on the other hand, is not in agreement with cascading theories, because they locate the cause of DLD in receptive phonological skills. Therefore, these theories hypothesized that receptive phonological skills could predict receptive syntactic skills later on in development, but not the other way around.

Implicit learning theories made the same predictions as cascading theories regarding the correlations at measurement points 1 and 2 and the correlations between the phonological and syntactic progress of children with DLD, although the reasoning behind the same hypotheses is different. The implicit learning theories would explain the positive correlations found in this study by suggesting that toddlers who have more severe implicit learning deficits would perform poorer on syntactic as well as on phonological tests than toddlers who have less severe implicit learning deficits. Furthermore, toddlers with more severe deficits would improve less in both domains than toddlers with less severe deficits. However, these theories do not provide explanations on why correlations were only found within the receptive and expressive domains. The explorative qualitative results on the different phonological diagnoses, on the other hand, can be explained by implicit learning theories. The results suggested that there were differences in syntactic performance between toddlers who made consistent phonological errors and toddlers who made inconsistent phonological errors. It could be hypothesized that toddlers with a consistent phonological disorder do have a system with phonological rules, although these rules are not always correct, while toddlers with an inconsistent phonological disorder do not have a rule system at all. To build a phonological rule system, one must detect structures in the input. It could be that toddlers who are diagnosed with an inconsistent disorder have more severe implicit learning deficits than toddlers diagnosed with a consistent disorder. This in turn, could lead to the differences between these two groups of toddlers, as suggested by the descriptive analyses in Section 5.4. However, these were only explorative descriptive analyses, so no conclusions can be drawn from this data and further research is therefore needed to examine this issue more thoroughly.

To sum up, the results of the present study are mostly in agreement with the predictions made by the cascading and implicit learning theories. However, not all predictions made by the cascading theories are borne out, and the implicit learning theories cannot explain the differences found between receptive and expressive abilities. The predictions made by the Bucket theory cannot entirely be ruled out either at this moment, although it is argued that the predictions made by this theory are unlikely to occur. The predictions made by the grammatical theory, on the other hand, are not in agreement with the findings of this study. The present study suggests that relations between phonological and syntactic abilities should be taken into account in any theory of DLD.

6.3 Limitations and further directions

The results of the present study suggest that phonological and syntactic abilities of toddlers with DLD are related. However, the confidence intervals in the correlation analyses were rather large, indicating that the results should be interpreted with care. Furthermore, there are a number of limitations to this study, which should be taken into account when interpreting the results.

Firstly, as mentioned above, the phonological and syntactic measurements were not always administered at the same time points. Therefore, the correlations that were found at the first and second measurement points, were in fact not correlations at the same time points. Rather, they were correlations between phonological and syntactic performances at two different points in development, although with the same time span in between these measurement points. In the present study, this could not have been done differently, because there was not always data available on phonology and syntax at the same time points. However, the fact that correlations were found between the first phonological and syntactic measurements, the second measurements, and between the first phonological/syntactic and second syntactic/phonological measurements, still indicates a relation between phonological and syntactic development of toddlers with DLD. Further research is needed in which phonological and syntactic abilities are assessed at the same time points to examine these relations in a more proper manner.

Secondly, the toddlers in the current study participated in a phonological intervention study. The phonological tests were assessed before (measurement 1) and after (measurement 2) the added intervention to usual care. Because the treatment of these toddlers focused on their phonological abilities more than usually, the second phonological measurement and their phonological progress did not reflect regular phonological development of toddlers with DLD. It is, therefore, uncertain whether similar correlations would have been found if the toddlers had not received this additional phonological intervention. It was indeed found that toddlers would not have improved or would have improved less in their phonological skills during their development when they had not received an additional intervention (van Lieburg, Ottow-Henning & Keij, under review). To address this issue, further research should examine phonological and syntactic improvement when no additional intervention is provided to the children.

Thirdly, the toddlers who participated in the current study were selected on their phonological impairments. Therefore, it should be noted that the relations found between phonological and syntactic abilities could only hold for toddlers with DLD and SSD. Further research is needed to explore these relations in other groups of children with DLD, because this can provide insight into whether relations between phonological and syntactic difficulties are common in all children with DLD.

A fourth limitation of this study is the relatively low number of participants that were part of the second measurement and the repeated mixed effects analyses. The large confidence intervals are most likely caused by this limitation. Including more participants would lead to more reliable results, and is thus suggested for further research.

A last issue to keep in mind is that it could be that the relations between phonological and syntactic scores were only found because of differences in how far along the toddlers were in their natural language development. It is possible that children who are further along in their language development score better on both phonology and syntax than children who are less far along in their language development. However, the results of the present study still indicate that children differ in their receptive and expressive development. To examine this issue, further research could measure the expressive and receptive skills in other language domains, such as vocabulary and pragmatics, as well.

As a future direction, it would be interesting to use a more extensive syntactic test as index for syntactic development than the Schlichting test. In the current study, there was little variation in the scores on the Schlichting test, especially in the syntactic production part. Using a more extensive test, more subtle differences between the syntactic abilities of toddlers could be found. Because the current study found some relational trends between receptive and expressive phonological and syntactic abilities at concurrent time points, it is possible that a more extensive test can show correlations between phonological and syntactic abilities across the receptive and expressive domain, which the Schlichting test could not.

Another future direction would be to see whether intervention in the receptive domain could have positive effects in other, non-treated, receptive abilities. Based on the results of the current study it could be hypothesized that intervention in the receptive domain would positively affect receptive abilities in a non-treated linguistic domain as well, because of the relations that were found. However, the current study did not examine the effect of the phonological intervention on syntactic performance. Furthermore, the intervention studies that were discussed in the theoretical background (see Section 2.4.2) only examined cross-domain effects within the expressive domain. These studies found mixed results, probably caused by different methods and measures. Cross-domain effects of an receptive intervention would be interesting to examine, because it could have implications for the kind of interventions speech and language pathologists could provide to children with DLD.

6.4 Clinical implications

Clinicians and speech and language pathologists should be aware of the relations between phonological and syntactic difficulties of children with DLD found in the current study, because these relations can have implications for the interventions they provide to children with DLD. The results indicate, for instance, that it is likely that a child with receptive syntactic difficulties also has receptive phonological difficulties. Since receptive phonological difficulties can influence how much of the input a child processes, pathologists should therefore also focus on the receptive phonological abilities of the child.

Furthermore, children who have more severe phonological/syntactic difficulties are likely to have more severe syntactic/phonological difficulties as well, within the expressive or receptive domain. Thus, based on information about performance in one linguistic domain (i.e. phonology or syntax), clinicians and speech and language pathologists can make predictions about performance in the other linguistic domain (i.e. syntax or phonology), which they could test in order to provide more accurate interventions matching the child's needs. If pathologists notice, for instance, expressive phonological difficulties of a child, they should also test expressive syntactic abilities in order to see whether the child has difficulties in this domain too.

The current results suggest that when speech and language pathologists treat phonological or syntactic difficulties in toddlers with DLD, and if toddlers improve in this treated ability, the pathologists could also expect effects of the treatment in syntactic or phonological abilities respectively. However, because the current study only examined relations between phonological and syntactic abilities and did not examine cross-domain effects of an intervention, this can only be seen as a likely prediction. Because the intervention studies described in Section 2.4.2 found mixed results regarding cross-domain effects, further research is needed to address this issue.

Finally, the qualitative analyses on the different phonological diagnoses seemed to suggest that children diagnosed with a consistent phonological disorder differ from children with an inconsistent phonological disorder in their syntactic performance. If this is the case, it would mean that phonological diagnoses influence syntactic performance. Therefore, it would mean that speech pathologists can make predictions about a child's syntactic performance based on their phonological diagnosis, and testing this could lead to interventions capturing all the difficulties of the child. However, because no conclusions could be drawn from these descriptive analyses, further research is needed to examine these differences.

To sum up, based on the current study, the main recommendation for clinicians and speech and language pathologists is that when they notice that a child has difficulties in either phonology or syntax, they should also test whether the child has difficulties in syntax or phonology respectively, especially within the same domain (i.e. expressive or receptive domain). This can lead to interventions that cover the phonological as well as the syntactic needs of a child with DLD.

7. Conclusion

The current study examined the relation between phonological and syntactic difficulties of toddlers with DLD. It comprised a concurrent and longitudinal examination of receptive and expressive phonological and receptive and expressive syntactic scores. The results indicate that the phonological and syntactic abilities of toddlers with DLD are related at concurrent time points, but only within the receptive and expressive domains. Furthermore, the results show that improvement in expressive phonological abilities is related to improvement in expressive syntactic abilities, and that improvement in receptive phonological abilities is related to improvement in receptive syntactic abilities. Finally, a descriptive analysis suggests that toddlers diagnosed with an inconsistent phonological disorder have lower syntactic scores than toddlers diagnosed with a consistent phonological disorder, which provides further support for the finding that phonological and syntactic abilities of toddlers with DLD are related.

This study contributes to our understanding of how different components of language interact during the language development of children with DLD. More specifically, it provides insight into how receptive and expressive phonological skills affect syntactic comprehension and production in toddlers with DLD, and vice versa. This study could have implications for clinicians and speech and language pathologists, as the interactions across these domains could be used in future interventions for toddlers with DLD.

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Appendix 1. Output expressive mixed effects analysis

```
MIXED Score3 BY MLD
  /FIXED=MLD | NOINT SSTYPE(3)
  /METHOD=ML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=MLD | SUBJECT(Kindnr) COVTYPE(UNR)
  /EMMEANS=TABLES(MLD) COMPARE ADJ(BONFERRONI).
```

Model Dimension[a]

		Number of Levels	Covariance Structure	Number of Parameters	Subject Variables	Number of Subjects
Fixed Effects	MLD	4		4		
Repeated Effects	MLD	4	Unstructured Correlations	10	Kindnr	25
Total		8		14		

a. Dependent Variable: Score.

Fixed effects

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
MLD	4	25,000	228,672	,000

a. Dependent Variable: Score.

Estimates of Fixed Effects[a]

Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
[MLD=11,][4]	4,040000	,167809	25,000	24,075	,000	3,694390	4,385610
[MLD=12]	3,600000	,411825	25,000	8,742	,000	2,751830	4,448170
[MLD=21]	4,640000	,155229	25,000	29,891	,000	4,320300	4,959700
[MLD=22]	6,760000	,490812	25,000	13,773	,000	5,749155	7,770845

a. Dependent Variable: Score.

[3] Score is either the PMLU or the score on the syntactic production part of the Schlichting test
[4] MLD=11 stands for Measurement 1, PMLU, MLD=12 for Measurement 1, syntactic production, MLD=21 for Measurement 2, PMLU, and MLD=22 for Measurement 2, syntactic production

Covariance parameters

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error	Wald Z	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Repeated Measures	Var(1)	,704000	,199121	3,536	,000	,404405	1,225544
	Var(2)	4,240000	1,199253	3,536	,000	2,435621	7,381116
	Var(3)	,602400	,170384	3,536	,000	,346042	1,048675
	Var(4)	6,022400	1,703392	3,536	,000	3,459501	10,483970
	Corr(2,1)	,571857	,134596	4,249	,000	,252691	,778783
	Corr(3,1)	,874050	,047207	18,515	,000	,743380	,940456
	Corr(3,2)	,397953	,168327	2,364	,018	,029213	,671356
	Corr(4,1)	,575794	,133692	4,307	,000	,258177	,781082
	Corr(4,2)	,566768	,135755	4,175	,000	,245629	,775803
	Corr(4,3)	,534257	,142914	3,738	,000	,201303	,756541

a. Dependent Variable: Score.

Estimated Marginal Means

Estimates[a]

MLD	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
11	4,040	,168	25,000	3,694	4,386
12	3,600	,412	25,000	2,752	4,448
21	4,640	,155	25,000	4,320	4,960
22	6,760	,491	25,000	5,749	7,771

a. Dependent Variable: Score.

Pairwise Comparisons[a]

(I) MLD	(J) MLD	Mean Difference (I-J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
11	12	,440	,345	25	1,000	-,547	1,427
	21	-,600*	,082	25,000	,000	-,835	-,365
	22	-2,720*	,417	25	,000	-3,916	-1,524
12	11	-,440	,345	25	1,000	-1,427	,547
	21	-1,040	,378	25	,065	-2,123	,043
	22	-3,160*	,426	25,000	,000	-4,380	-1,940
21	11	,600*	,082	25,000	,000	,365	,835
	12	1,040	,378	25	,065	-,043	2,123
	22	-2,120*	,428	25	,000	-3,348	-,892

22	11	2,720*	,417	25	,000	1,524	3,916
	12	3,160*	,426	25,000	,000	1,940	4,380
	21	2,120*	,428	25	,000	,892	3,348

Based on estimated marginal means

*. The mean difference is significant at the ,05 level.

a. Dependent Variable: Score.

c. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests[a]

Numerator df	Denominator df	F	Sig.
3	25,000	34,395	,000

The F tests the effect of MLD. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.[a]

a. Dependent Variable: Score.

Appendix 2. Output receptive mixed effects analysis

```
MIXED Score5 BY MLD
  /FIXED=MLD | NOINT SSTYPE(3)
  /METHOD=ML
  /PRINT=SOLUTION TESTCOV
  /REPEATED=MLD | SUBJECT(Kindnr) COVTYPE(UNR)
  /EMMEANS=TABLES(MLD) COMPARE ADJ(BONFERRONI).
```

Model Dimension[a]

		Number of Levels	Covariance Structure	Number of Parameters	Subject Variables	Number of Subjects
Fixed Effects	MLD	4		4		
Repeated Effects	MLD	4	Unstructured Correlations	10	Kindnr	25
Total		8		14		

a. Dependent Variable: Score.

Fixed effects

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
MLD	4	23,275	144,351	,000

a. Dependent Variable: Score.

Estimates of Fixed Effects[a]

						95% Confidence Interval	
Parameter	Estimate	Std. Error	df	t	Sig.	Lower Bound	Upper Bound
[MLD=11][6]	9,955988	,608281	24,245	16,367	,000	8,701228	11,210748
[MLD=12]	19,640000	1,842503	25,000	10,659	,000	15,845295	23,434705
[MLD=21]	11,768137	,529235	24,316	22,236	,000	10,676600	12,859673
[MLD=22]	32,920000	1,936529	25,000	16,999	,000	28,931644	36,908356

a. Dependent Variable: Score.

[5] Score is either the score on the MPT or the score on the syntactic comprehension part of the Schlichting test
[6] MLD=11 stands for Measurement 1, MPT, MLD=12 for Measurement 1, syntactic comprehension, MLD=21 for Measurement 2, MPT, and MLD=22 for Measurement 2, syntactic comprehension

Covariance parameters

Estimates of Covariance Parameters[a]

Parameter		Estimate	Std. Error	Wald Z	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Repeated Measures	Var(1)	9,093185	2,637537	3,448	,001	5,150145	16,055083
	Var(2)	84,870400	24,004974	3,536	,000	48,752860	147,744867
	Var(3)	6,815036	1,972283	3,455	,001	3,864817	12,017313
	Var(4)	93,753600	26,517522	3,536	,000	53,855715	163,209001
	Corr(2,1)	,684957	,107336	6,381	,000	,415370	,843938
	Corr(3,1)	,531621	,159108	3,341	,001	,156406	,772744
	Corr(3,2)	,351723	,180396	1,950	,051	-,036061	,647449
	Corr(4,1)	,713362	,104003	6,859	,000	,445390	,864037
	Corr(4,2)	,844955	,057210	14,769	,000	,689107	,926096
	Corr(4,3)	,491705	,151998	3,235	,001	,144385	,731159

a. Dependent Variable: Score.

Estimated marginal means

Estimates[a]

MLD	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
11	9,956	,608	24,245	8,701	11,211
12	19,640	1,843	25,000	15,845	23,435
21	11,768	,529	24,316	10,677	12,860
22	32,920	1,937	25,000	28,932	36,908

a. Dependent Variable: Score.

Pairwise Comparisons[a]

(I) MLD	(J) MLD	Mean Difference (I-J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
11	12	-9,684*	1,498	24,946	,000	-13,975	-5,393
	21	-1,812*	,562	20,664	,025	-3,451	-,174
	22	-22,964*	1,566	24,548	,000	-27,459	-18,469
12	11	9,684*	1,498	24,946	,000	5,393	13,975
	21	7,872*	1,732	24,866	,001	2,909	12,835
	22	-13,280*	1,056	25,000	,000	-16,305	-10,255
21	11	1,812*	,562	20,664	,025	,174	3,451
	12	-7,872*	1,732	24,866	,001	-12,835	-2,909
	22	-21,152*	1,742	25,099	,000	-26,142	-16,162

22	11	22,964*	1,566	24,548	,000	18,469	27,459
	12	13,280*	1,056	25,000	,000	10,255	16,305
	21	21,152*	1,742	25,099	,000	16,162	26,142

Based on estimated marginal means

*. The mean difference is significant at the ,05 level.

a. Dependent Variable: Score.

c. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests[a]

Numerator df	Denominator df	F	Sig.
3	23,733	94,634	,000

The F tests the effect of MLD. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.[a]

a. Dependent Variable: Score.