From Group Results to Individual Patterns in Pronoun Comprehension

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1. Delay of Principle B Effect

A well-studied phenomenon in language acquisition is the acquisition of pronouns and reflexives (e.g., Chien & Wexler, 1990; Jakubowicz, 1984; Koster, 1993; Philip & Coopmans, 1996; Spenader, Smits, & Hendriks, 2009). The adult use of reflexives and pronouns can be described by Principles A and B of Binding Theory (Chomsky, 1981).

(1) a. Principle A: a reflexive must be bound in the local domain.
 b. Principle B: a pronoun must be free in the local domain.

Here, the local domain is defined as the minimal clause that contains both the lexical anaphor and a subject. An anaphor is bound when it is co-indexed with and c-commanded by an antecedent. To illustrate the application of the binding principles, consider sentences (2a) and (2b).

(2) a. The penguin$_i$ is hitting himself$_{i/*j}$ with a pan.
 b. The penguin$_i$ is hitting him$_{*i/j}$ with a pan.

According to Principle A, the reflexive *himself* in (2a) has to co-refer with the subject of the local domain, *the penguin*. Principle B states that a pronoun must be locally free, which means that a pronoun cannot co-refer with the subject in the local domain. As a result, the pronoun *him* in (2b) cannot co-refer with *the penguin*, but must refer to another antecedent present in the context. Given the similarity between Principles A and B, it is expected that the acquisition of reflexives and pronouns proceeds at a comparable speed. However, although children show adult-like performance on reflexive comprehension from the age of 3;0 on, they have been shown to experience difficulties in the interpretation of pronouns up to the age of 6;6 by incorrectly allowing the pronoun to corefer with the local subject (e.g., Chien & Wexler, 1990). This delay in the acquisition of pronoun comprehension is called the Delay of Principle B-Effect (DPBE). On the other hand, it has recently been shown that children can *produce* reflexives and pronouns correctly from the age of 4;6 on (e.g., De Villiers, Cahillane, & Altreuter, 2006; Spenader et al., 2009). So there seems to be a second asymmetry in the acquisition of pronouns, namely between comprehension and production. As yet there is no general consensus on what causes these asymmetries. Explanations for the DPBE range from a deficiency in pragmatic skills (e.g., Thornton & Wexler, 1999), the effects of an unbalanced context (e.g., Conroy, Takahashi, Lidz, & Phillips, 2007) and working memory limitations (e.g., Reinhart, 2006) to the inability to optimize bidirectionally (Hendriks & Spenader, 2005/2006).

2. Computational simulation of the DPBE

Hendriks, van Rijn and Valkenier (2007) developed a computational model accomodating Hendriks and Spenader's (2005/2006) account of the DPBE. This computational model was implemented within the cognitive architecture ACT-R (Anderson et al., 2004), a modeling environment that constrains simulation models to ensure psychological plausibility. This architecture has previously been used to model both developmental (e.g., Van Rijn, Van Someren, & Van der Maas, 2003) and language phenomena (e.g., Lewis & Vasishth, 2005). The DPBE/ACT-R model referred to in this paper is a refined implementation of Hendriks et al. (2007), that enables us to derive more precise predictions related to the DPBE. In this section, only the main predictions of the model will be discussed (see Van Rij, Hendriks, Spenader, & Van Rijn, to appear, for a more extensive description of the model and its predictions).

2.1 Simulating children's performance

Hendriks and Spenader (2005/2006) argue that the DPBE can be explained as resulting from the direction-sensitivity of a constraint-based grammar such as Optimality Theory (OT; Prince & Smolensky, 2004). In OT, production can be modeled as a process of optimization from an input meaning to the optimal form to express that meaning. Similarly, comprehension can be modeled as a process of optimization in the opposite direction, namely from an input form to the optimal meaning for that form. The optimal form or meaning is selected on the basis of a set of ranked and violable constraints. Crucially, these constraints are direction-sensitive and can have different effects in the two directions of optimization.

It is shown by Hendriks and Spenader (2005/2006) that the same set of partly direction-sensitive constraints can be responsible for children's different performance in pronoun production and pronoun comprehension. Assuming Principle A and a direction-sensitive constraint preferring forms with less referential content over forms with more referential content, pronouns are predicted to be ambiguous in comprehension, allowing disjoint reference with the subject as well as coreference. In production, on the other hand, disjoint reference with the local subject is optimally expressed by a pronoun and coreference with the subject is optimally expressed by a reflexive.

2.2 Simulating adults' performance

Children's pattern of non-adult comprehension and adult-like production can be modeled as *unidirectional optimization*: optimization from form to meaning in comprehension, and from meaning to form in production. This formalizes the intuitive idea that children only consider their own perspective as a hearer or speaker. In contrast, adults have been argued to take into account the perspective of the conversational partner in pronoun comprehension (Hendriks & Spenader, 2005/2006). As a consequence pronouns are not ambiguous for adults. Our DPBE/ACT-R model simulates adult pronoun comprehension as two consecutive steps of unidirectional optimization: 1) selecting the optimal meaning for the (ambiguous) pronoun, and 2) checking whether a speaker would have expressed this meaning with the same form. This process, equivalent to *bidirectional optimization* in OT (Blutner, 2000), is illustrated schematically in Figure 1:

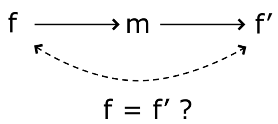

Figure 1. Bidirectional optimization in comprehension: taking into account the speaker's perspective.

When the model encounters a pronoun while simulating a hearer, in the first step the model determines the optimal meaning for this form. This is done on the basis of the constraints of the grammar. This first step describes children's comprehension of pronouns. If several optimal candidate exist, one of the optimal candidates is randomly selected and marked as the optimal candidate. In the second step, the model takes the perspective of the speaker, and determines the optimal form to express the selected meaning. The input of this second process of unidirectional optimization consists of the selected optimal meaning that was the output of the first step. If the input form (in this case a pronoun) and the optimal form to express the selected meaning are identical, then the model concludes that the speaker intended to express the selected meaning. This strategy has the effect of disambiguating pronouns. For example, if the model in the first step selects a coreferential interpretation as the optimal meaning for a pronoun, then the model will discover in the second step that a coreferential interpretation is optimally expressed with a reflexive. Because the input form (the pronoun) is not identical to the output form (the reflexive), the coreferential interpretation is blocked for a pronoun.

So, in the model, Principle B of Binding Theory is not part of the grammar but rather is a derived effect. It results from the process of also taking into account the opposite direction of optimization. The model predicts that adult hearers have no difficulties with pronoun comprehension, because they perform both steps of the optimization process and hence take into account the perspective of the speaker. As a consequence, pronouns are not ambiguous anymore. The question is what keeps children from using bidirectional optimization.

2.3 Acquisition of adult-like performance

An assumption of ACT-R that is important for this study is the assumption that every cognitive operation takes a certain amount of time. Because bidirectional optimization is simulated as two consecutive processes of unidirectional optimization, bidirectional optimization takes more time than unidirectional optimization. The amount of time available for bidirectional optimization is limited, because the speaker determines the speed of the speech directed to children. If children's speed of processing is not fast enough to perform bidirectional optimization within the given amount of time, pronouns remain ambiguous and a guessing pattern emerges. The model assumes that children already know how to apply bidirectional optimization. However, initially, they cannot complete both processes of unidirectional optimization within the available amount of time, because their processing efficiency is not high enough. In the ACT-R architecture, higher processing efficiency can be obtained through the production compilation mechanism (Taatgen & Anderson, 2002). Production compilation is a learning mechanism that makes a process more efficient when it is repeatedly performed. Eventually, children's unidirectional optimization processes are performed fast enough so that two unidirectional processes can be completed in the given time, resulting in a bidirectional optimization process. As soon as this is achieved, pronouns are correctly disambiguated.

In conclusion, the model predicts that children's speed of processing is the factor that determines whether children show the DPBE. In other words, the DPBE/ACT-R model assumes that children have the ability to optimize bidirectionally, but lack the processing efficiency to do so. So, when children who show the DPBE are given more time, the model predicts that their performance on pronoun interpretation will improve. However, children who do not show a DPBE anymore are not expected to benefit from slowed-down speech, because they already are able to interpret pronouns correctly.

3. Experimental design

We performed a psycholinguistic experiment to investigate the prediction of the DPBE/ACT-R model that the DPBE arises because of children's limited speed of processing. The result of their limited processing speed is that children as hearers are unable to take into account the speaker's perspective. We investigated this prediction by comparing children's comprehension of pronouns at a normal speech rate with their comprehension of pronouns at a slower speech rate. Slowing down the speech rate will give children more time for interpretation. We predicted that the performance of children showing the DPBE on pronoun comprehension will increase as an effect of slowed-down speech. However, no increase in performance is expected on reflexive comprehension.

3.1 Methods en materials

A Truth Value Judgment Task was used to test Dutch children's comprehension of pronouns and reflexives. Children were asked to judge whether a test sentence like (3) is a good description of a picture that is shown on a computer screen.

(3) Kijk, een pinguïn en een schaap zijn op de stoep.
De pinguïn slaat hem / zichzel met een pan.
'Look, a penguin and a sheep are on the sidewalk.
The penguin is hitting him / himself with a pan.'

Half of the sentences were combined with a matching picture and the other half were presented with a non-matching picture (see Figure 2).

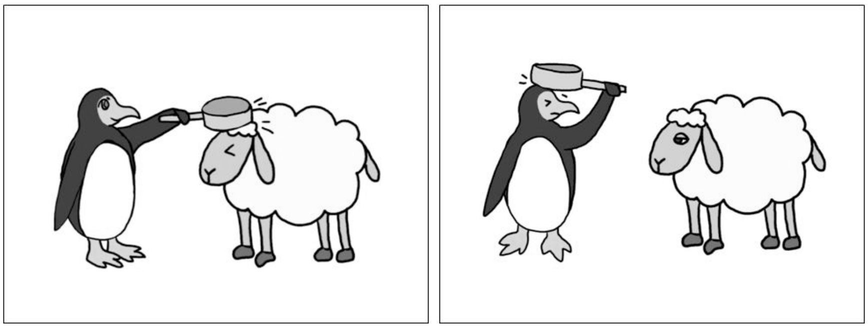

Figure 2. The pictures that were presented with the sentences in (3).

The verbs that were used are *bijten* (to bite), *kietelen* (to tickle), *schminken* (to make up), *wijzen naar* (to point at), *slaan* (to hit), and *vastbinden* (to tie up). These verbs are selected to avoid a bias towards a coreferential interpretation, because they all are more likely to be used to describe an other-directed action (Spenader et al., 2009). The same verbs were used in the two speech rate conditions of the experiment, but the selected actors and instruments were different between conditions.

The sentences were prerecorded at a normal speech rate. Sentences for the slow speech rate condition were digitally slowed-down using the software Adobe Audition 1.5, while keeping the pitch constant. The mean speech rate of the normal speech rate sentences is 4.0 syllables per second and the slow speech rate sentences were stretched 1.5 times, resulting in a mean speech rate of 2.7

syllables per second (cf., Montgomery, 2004; Weismer & Hesketh, 1996). Every participant was tested in both speech rate conditions. Every condition contained 8 pronoun sentences, 8 reflexive sentences and 4 control sentences to measure the participants' general performance on the task.

3.2 Participants

Seventy-five children between 4;1 and 6;3 years old were tested. They were all recruited from a Dutch local elementary school. From these 75 children, 13 were excluded from further analysis (4 children were bilingual or nonnative Dutch speakers, 5 did not finish the task, and 4 responded incorrectly to more than two out of eight control items). The data of the remaining 62 children (35 boys and 27 girls), ranging in age from 4;1 to 6;2, were used for statistical analysis.

4. Results

4.1 General Results

Figure 3 presents the performance of the 62 participants on pronoun sentences (left) and reflexive sentences (right) in the two speech rate conditions.

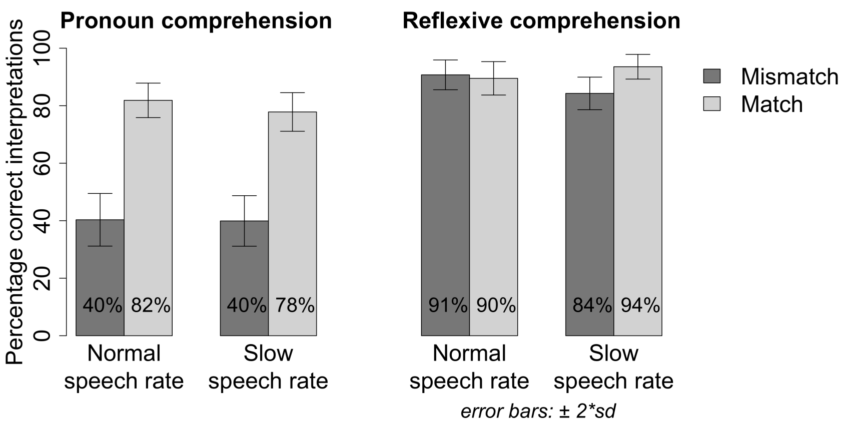

Figure 3. Mean percentages of correct interpretations of pronoun and reflexive sentences in the two speech rate conditions, for all children (n=62).

Figure 3 shows that the children perform better on reflexive comprehension than on pronoun comprehension, replicating earlier studies (e.g., Philip & Coopmans, 1996; Spenader et al., 2009). This difference in performance is statistically significant in both conditions (normal speech rate: paired $t(61)=8.9$, $p<0.001$; slow speech rate: paired $t(61)=9.5$, $p<0.001$). Furthermore, for pronoun sentences the participants show better performance on match items (normal speech rate: 82%, slow speech rate: 78%) than on mismatch items (normal speech rate and slow speech rate: 40%). This difference in percentages correct interpretations between match an mismatch items is also statistically significant (normal speech rate: paired $t(61)=8.764$, $p<0.001$; slow speech rate: paired $t(61)=6.810$, $p<0.001$). This difference is caused by a yes-bias (see also Chien & Wexler, 1990; Grimshaw & Rosen, 1990). However, no significant difference in performance was found between the two speech rate conditions on pronoun or reflexive sentences ($t<1$).

4.2 Classification of participants

A closer look at the individual data reveals that participants showed different, and sometimes even opposite, behavior on the task. These differences in behavior may have masked a possible effect of slowed-down speech on pronoun comprehension. As only those children who displayed the DPBE were predicted to show increased performance with slowed-down speech, we analyzed the behavior of the individual participants on the task to be able to distinguish the children who showed the DPBE from the children who clearly did not. The following groups were defined (see also Figure 4):
i. *Correct Performance group*. This group consists of children who show (almost) correct performance on pronoun and reflexive sentences, thus not showing a DPBE (n=14; 9 boys, 5 girls; age 4;2-6;0, mean 5;5). Children were classified as belonging to this group if the mean percentages of correct interpretations on reflexive and pronoun sentences in the normal speech rate condition both were 80% or more.
ii. *No DPBE group.* This group consists of children who did not show the DPBE, because they displayed incorrect performance (less than 80% correct interpretations) on pronoun and reflexive sentences, and in addition displayed the same amount or fewer correct interpretations on reflexive sentences as on pronoun sentences at normal speech rate (n=5; 3 boys, 2 girls; age 4;3-4;7, mean 4;5).
iii. *Extra-Linguistic Strategy group.* The children who are classified as belonging to this group used the extra-grammatical strategy of answering ‘yes’ to all pronoun mismatch items in both speech rate conditions (n=9; 3 boys, 6 girls; age 4;10-6;2, mean 5;7).
iv. *DPBE group.* All children who were not classified as one of the other three groups, were expected to show the DPBE: they showed incorrect (less than 80% correct) performance on pronoun sentences, but better performance on reflexive sentences (n=34; 19 boys, 15 girls; age 4;1-6;2, mean 4;11).

A between group ANOVA showed that these groups differ significantly $F(3,61)=8.533$, $p<0.001$). Post hoc analysis (pairwise comparisons using t-tests with pooled standard deviations) of the mean age between the four groups showed the following significant differences: between the No DPBE group and the Extra-Linguistic Strategy group ($p < 0.001$, all p-values are adjusted using a

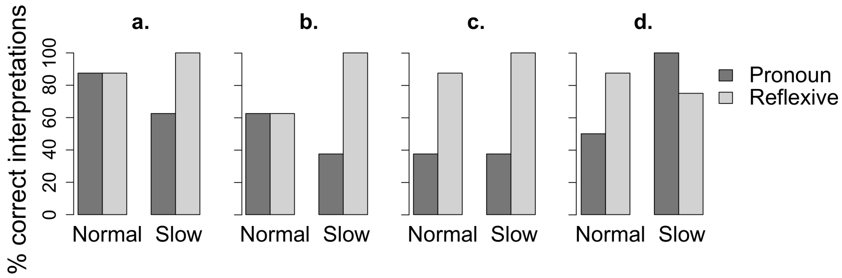

Figure 4. Examples of the performance on pronoun and reflexive comprehension of a child from a.) the Correct Performance group, b.) the No DPBE group, c.) the Extra-Linguistic Strategy group (percentages are the means of match and mismatch items) and from d.) the DPBE group.

α/6 Bonferroni correction), between the No DPBE group and the Correct Performance group (p=0.004), between the Extra-Linguistic Strategy group and the DPBE group (p=0.005), and between the DPBE group and the Correct Performance group (p=0.040). No significant difference in age was found between the No DPBE group and the DPBE group (p > 0.1) and between the Extra-Linguistic Strategy group and the Correct Performance group (p > 0.1).

4.3 Results of the DPBE group

In this experiment we are primarily interested the results of the children who showed the DPBE, because the DPBE/ACT-R model only predicts a beneficial effect of slowed-down speech on pronoun comprehension for this group. Figure 5 displays the percentages correct interpretations on pronoun (left) and reflexive sentences (right) for the two speech rate conditions.

To investigate whether slowed-down speech has a significant beneficial effect on pronoun comprehension, a repeated measures ANOVA was performed on the arcsine transformation of the proportion correct interpretations. The included within-subject factors were: *Expected Answer* (type of test sentence: match or mismatch with picture), and *Speech Rate* (normal or slow). Because the sequence of the two speech rate conditions was counterbalanced across participants, the between-subjects factor *Block* was also included, specifying the sequence of the speech rate conditions (normal speech rate condition first versus slow speech rate condition first). The statistical analysis showed a marginal significant interaction between Expected Answer and Speech Rate (F(1,33)=3.904; p=0.057), and a significant main effect of Expected Answer (F(1,33)=54.436; p<0.001). The significant effect of Expected Answer reflects children's yes-bias, a tendency to answer 'yes' over 'no' when the answer is not certain (e.g., Chien & Wexler, 1990). Because children are assumed to say 'no'

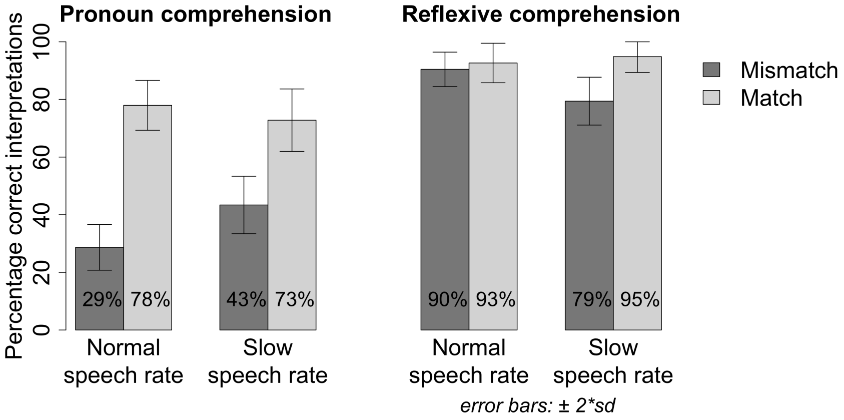

Figure 5. Mean percentages of correct interpretations of sentences with a pronoun or a reflexive in the two speech rate conditions, for the DPBE children (n=34).

only when they are highly certain about the answer, it makes sense to focus on the pronoun mismatch items. Figure 5 shows a difference in performance on pronoun mismatch items between the speech rate conditions (normal speech rate: 29%; slow speech rate: 43%). This difference is statistically significant (paired $t(33)=-2.512$; $p=0.017$). In contrast, no significant difference between the two speech rate conditions (normal speech rate: 78%; slow speech rate: 73%) was found on match items (paired $t(33)>0.1$). In general, it can be concluded that slowed-down speech has a significant beneficial effect on pronoun comprehension. For reasons of space, we do not present the statistical analysis of children's performance on reflexive sentences here, but see Van Rij, Hendriks, Spenader and Van Rijn (to appear) for these analyses, which suggest that slowed-down speech does not have an effect on reflexive comprehension.

4.4 Results of other groups

The model predicts no significant differences in performance on pronoun comprehension between the two speech rate conditions for children that show (almost) correct performance in the normal speech rate condition (the Correct Performance group). However, performing the same analysis as used for the data of the DPBE group, we found that the performance on pronoun comprehension in the slow speech rate condition significantly decreased ($F(1,13)=10.871$, $p=0.006$). The effect of Speech Rate is significant both for mismatch items (paired $t(13)=-3.647$, $p=0.003$) and match items (paired $t(13)=-2.687$, $p=0.019$). In addition, a significant effect of Expected Answer was found ($F(1,13)=14.731$, $p=0.002$), and also a marginal significant interaction effect between Expected Answer and Block ($F(1,12)=3.703$, $p=0.078$). These results suggest that slow speech may have a general negative effect on linguistic performance. The significant negative effect of slowed-down speech on pronoun comprehension for children that show already correct performance makes the significant positive effect of slowed-down speech in the DPBE group even more striking.

We also analyzed the data of the children who displayed incorrect performance on pronoun comprehension but did not display the DPBE (the No DPBE group) using the same repeated measures ANOVA's. Statistical analysis showed no significant effect on pronoun comprehension for the No DPBE group. This result follows from the model indirectly, as the model assumes that children can only succeed in bidirectional optimization if they have the ability to succeed in unidirectional optimization and thus should perform almost correctly on reflexive sentences. A repeated measures ANOVA of the data of children who used an extra-linguistic strategy (the Extra-Linguistic Strategy group) showed no significant difference in performance on pronoun sentences between the two speech rate conditions. Note that the use of extra-linguistic strategies was not implemented in the model. Therefore, no predictions can be formulated for the Extra-Linguistic Strategy group. However, from a theoretical perspective, these children are not expected to benefit from the larger amount of time that is available for interpretation, because they apparently do not use bidirectional optimization to find the optimal interpretation for pronouns.

5. Discussion

The experiment presented here was performed to investigate the hypothesis generated by our DPBE/ACT-R model that children show difficulties in the comprehension of pronouns as a result of their limited speed of processing. Because of their lack of processing speed, children cannot take into account the perspective of the speaker in comprehension. According to the DPBE/ACT-R model, this is necessary to resolve the pronominal ambiguity. In our study, we found that children perform significantly better on pronoun comprehension if speech is slowed down, but only if the children display a DPBE. No beneficial effects of slowed-down speech were found with pronoun comprehension for children who did not show the DPBE. These results support the hypothesis of the DPBE/ACT-R model (based on Hendriks et al., 2007) that children do not have sufficient time for taking into account the speakers' perspective.

These results also show that it is important to consider individual differences in participants' behavior on a psycholinguistic task. The general results showed a clear DPBE (cf., Chien & Wexler, 1990; Spenader et al., 2009), but more subtle effects in the data were masked because individual children showed different, and sometimes even contradictory, behavior. In many acquisition experiments, participants are divided into age groups to show that performance changes during children's development. However, our classification based on task behavior shows that the defined groups not necessarily differ in age. For example, the mean age of the children who showed (almost) correct performance on the task (age 4;2-6;0, mean 5;5) did not significantly differ from the mean age of children who used an extra-linguistic strategy for pronoun comprehension (age 4;10-6;2, mean 5;7), a strategy that gave rise to many errors on pronoun sentences. As a consequence, dividing the participants into groups based on age may lead to the masking of effects such as those of slowed-down speech. Because children's cognitive development shows individual variation, children of the same age may show different behavior on the same task (e.g., Jansen & Van der Maas, 2002).

6. Conclusion

In this study we investigated the effects of slowed-down speech on pronoun comprehension. Up to the age of 6, children have been shown to experience difficulties in the interpretation of pronouns by incorrectly allowing the pronoun to corefer with the local subject about half the time (e.g., Chien & Wexler, 1990). A computation model of the acquisition of pronoun comprehension (based on Hendriks et al., 2007) predicts that this Delay of Principle B effect (DPBE) arises because of children's limited speed of processing, as a result of which children are unable to take into account the speaker's perspective. This hypothesis was tested by comparing pronoun comprehension at a normal rate with slow speech, because slowing down the speech rate is a way of giving children more time for interpretation. In this study it was found that slower speech rate has a significant beneficial effect on children's comprehension of pronouns, but only if the child displays a DPBE. In general, slower speech rate seems to have a negative effect on comprehension. This supports the hypothesis that the DPBE is caused by children's insufficient speed of processing.

Acknowledgements

This investigation was supported in part by a grant from the Netherlands Organisation for Scientific Research, NWO, awarded to Petra Hendriks (grant no. 277-70-005). The authors thank the children, teachers and parents of the Nassauschool in Groningen for participating in the experiment, Petra van Berkum and Robert Prins for drawing the pictures used in the experiment, and Margreet Drok-van der Meulen for recording the sentences.

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