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Facilitating Quantifier Acquisition: Training Can Eliminate Children's Spreading Errors

Jennifer Spenader and Christian Roest

1. Introduction

When shown a picture of three girls building a sandcastle (Fig. 1), with a fourth completed sandcastle in the sentence, many children between the ages of 5;0-9;0 will reject sentences with universally quantified subjects like (1) as an accurate description. When asked why, children often explain that the fourth sandcastle doesn't have a girl.

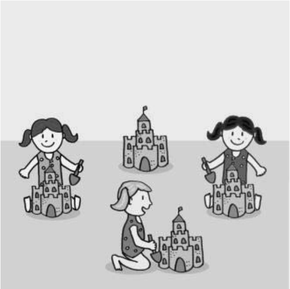

Figure 1. Extra Object Picture

(1) Each girl is building a sandcastle.

This well-known error with universal quantification is called spreading, (Roeper and Matthei, 1974), overexhaustive pairing, or symmetrical response (Philip, 1995). Spreading is pervasive, affecting all universal quantifiers, and experimentally shown to occur in many languages (see e.g. Philip 1995, Crain et al. 1996 and Drozd 2001; Drozd, 2017, de Koster et al. 2018). Spreading errors peak at age 7, and a substantial number of children still make errors at age 11-12 (Roeper et al., 2006).

A puzzling result found in many spreading experiments is that many children often show extreme response patterns: they either consistently spread or are adult-like. These patterns suggest children who spread are missing some crucial knowledge about quantifiers and how to restrict their domains.

However, many accounts of spreading claim children have full knowledge of the semantics of universal quantifiers. Instead, these accounts explain

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spreading as the results of pragmatic processing or underdeveloped executive functions, such as lower working memory capacity or weaker cognitive control.

If spreading errors are caused by a lack of quantifier knowledge, then training children to no longer make them should be possible. If spreading is due to insufficient working memory or cognitive control, a short training session should have little effect. With this in mind, we designed a training study, to gain more insight into what causes spreading and how children achieve adult-like interpretations.

2. Background

2.1. Semantic Quantifier Interpretation

Briefly, semantic theory tends to analyze quantifiers as signaling relations between two sets (Generalized Quantifier Theory, Barwise and Cooper, 1981). In (1), the set of girls is termed the restrictor set, while the set of sandcastle builders is termed the scopal set. The quantifier identifies the constraints on the relationship between the two sets for the sentence to be true. In (1), the restrictor set (the set of girls), needs to be a subset of the scopal set (the set of sandcastle builders). This subset relation is signaled by all universal quantifiers (e.g. *each, every* and *all*). Importantly, extra sandcastle builders and additional sandcastles are not relevant. However, children's explanations of spreading errors suggest they are concerned about these other sets, and take them into consideration when asked to judge the truth of a universally quantified sentence.

Spreading errors seem to be evidence that children master different aspects of the semantics of universal quantification at different times. For example, very young children sometimes make underexhaustive errors, accepting a sentence like (1) even in a situation where some girls are not building sandcastles. These errors disappear around age 4;0. Children who make spreading errors usually no longer make underexhaustive errors (see e.g. Aravind et al., 2017). But what causes spreading errors? The different explanations for spreading cover a large range of potential sources. The next section gives a brief overview, and also speculates on what each proposal predicts about the effects of training children will be.

2.2. Causes of Spreading

2.2.1. Syntactic Accounts of Spreading

A number of influential accounts of spreading consider its primary cause to be underdeveloped syntactic knowledge of quantificational determiners. Identifying the restrictor set requires recognizing which NP is a syntactic argument in the quantified DP. Philip (1995) and Roeper et al. (2006) both propose that initially children may treat universal quantificational determiners, as if they were sentential adverbial quantifiers like *always.* Children then mistakenly allow the quantifiers to quantify over the event in the sentence, rather than the individuals. Under this account sentences like (1) are interpreted like (2):

(2) Every event is a girl building a sandcastle event.

Eventually children do realize that quantificational determiners are syntactically associated with NPs in a DP. But in this second stage of acquisition they have trouble identifying the syntactically associated NP. This means that they sometimes incorrectly identify an NP in the predicate as the quantifier's restrictor (instead of part of the scope), interpreting (1) as *Every sandcastle is being built by a girl*.

Correctly identifying the syntactically associated NP can actually be tricky, because some quantificational determiners can be separated from their quantified material in the surface syntax, e.g. floated quantifiers:

(3) The girls build a sandcastle each.

Children therefore need time to figure out the structure, and learn to correctly determine the restrictor of DPs. Thus, under syntactic accounts, spreading errors are caused by not knowing how to correctly restrict the quantifier syntactically. It might therefore be possible to facilitate children's acquisition by giving them a short training that makes explicit how restrictor sets are identified.

2.2.2. Task Felicity Accounts of Spreading

Some influential accounts of spreading claim that children and adults both have complete knowledge of quantification. For example, Crain et al. (1996) argue that standard spreading tasks are pragmatically infelicitous, and actually encourage children to give spreading responses, even though they have adult-like knowledge of quantifiers.

Briefly, the standard picture verification tasks used to test quantifier knowledge usually present agents doing activities visually, without context, asking children a "yes-no" question about the picture. Crain et al. (1996) argue that for picture verification to be pragmatically natural, both "yes" and "no" answers should be real possibilities. However, target *Extra Object* conditions are misleading because there is no natural "no" answer. For example, asking a child "Is every girl building a sandcastle" with Fig. 1 doesn't seem like a genuine question unless there was a possibility that some of the girls would not build a sandcastle, or that some girls would build something else. Crain et al. (1996)'s experiments used frame stories that made both positive and negative responses natural, and the rate of spreading decreased substantially.

Two criticisms of this account are that in many other experiments there may not be a genuine "no" response available, but children do not make the types of errors seen in spreading (see Geurts 2003 and Roeper et al. 2006). Further, the frame story itself increases the salience of the intended restrictor set. We know from other studies that increasing the salience improves interpretations. Similarly, decreasing the visual salience of direct objects by using multiple extra objects lowers spreading rates (Sugisaki and Isobe, 2001; Minai et al., 2012) and so does using photographs with a natural background, which also makes additional objects less prominent (Kiss and Zetenyi, 2017).

If the pragmatic felicity of the experimental designs used to test spreading is a major cause of spreading responses, it might be possible to teach children to respond the way we want to such a task, but it is not clear if this task-specific training would carry over to other tasks. In order to evaluate this, we would need to test children with a different type of task than the one they are trained on.

2.2.3. Syntax-Semantics Interface Account

Like Crain et al. (1996), Geurts (2003) also proposes that children have complete knowledge of the meaning of quantifiers. Unlike Crain et al., Geurts attributes children's problems with quantifier interpretation to a problem with mapping syntactic structures onto semantic representations.

Geurts' accounts relies on the fundamental distinction between weak and strong quantifiers. Weak quantifiers, like *some* or *two,* do not always need the relational analysis of Generalized Quantifier Theory. Instead sentences with weak quantifiers, like e.g. *Two girls built a sandcastle*, can be analyzed as a two-part relationship between the quantifier and the conjunction of girls and sandcastle builders. The quantifier then simply defines the required cardinality of the conjoined sets as two.

However, strong quantifiers require a relational analysis, because they are asymmetrical. Geurts suggests that working memory limitations, or problems with attention might lead children to incorrectly map both the restrictor and scopal sets to the scopal position, similar to a weak quantifier representation. After mapping this syntax to semantics, the restrictor position remains empty. The child can repair this flawed structure by using pragmatics: whatever sets are more salient in the context will end up being interpreted as the restrictor set. When a set contributed by the predicate is pragmatically more salient, spreading errors will occur. Under this proposal, children become adult-like as they mature, increasing their working memory capacity and their "attention".

In a recent experiment de Koster et al., (2018) did not find a relation between spreading and working memory. But what Geurts (2003) terms "attention" is probably synonymous with cognitive control. Minai et al. (2012) found that high rates of spreading correlated with poorer performance on the DSSC sorting task, suggesting that lack of sufficient cognitive control (perhaps allowing one to ignore irrelevant (visual) cues), contributes to spreading. This result aligns nicely with Geurts' account. When confronted with visual contexts where the scopal set is salient, children with poor cognitive control are less able to ignore additional objects, even though the grammar, and often many other non-visual factors (e.g. favor agents as the restrictor set or favor NPs near the quantifier) may conflict with the pragmatic choice. For those children, spreading will dominate their responses.

Working memory capacity and cognitive control cannot be trained in a single session, so Geurts' account does not predict that training will have any substantial effect on rates of spreading.

Finally, note that the first researchers to publish on spreading errors, Inhelder & Piaget (1964), considered it part of a developmental stage. Because developmental stages cannot be trained away, this classic account also does not predict that training will help.

In summary, accounts like Crain et al. (1996) or Geurts (2003), where spreading is attributed to problems with pragmatic felicity or executive function development, do not predict that children will show improvements in interpreting universal quantifiers after a short training session. However, syntactic accounts such as Roeper et al. (2006) suggest that training children to correctly identify the restrictor set might facilitate their acquisition. For this reason we designed a training study to expose children more explicitly to the meaning of universally quantified sentences.

2.3. Features of our study

Given the errors children make and the syntactic accounts of spreading, two points should be featured in the training. First, it should be emphasized how to identify the restrictor set, and second, it should be clearly pointed out that the scopal set does not have to be exhausted, and additional objects are irrelevant.

Standardly spreading is diagnosed with picture verification, so we wanted to use this method for screening children and testing after training. But for the actual training we chose to use an act-out task in order to avoid training for th exact testing method. Using manipulable objects also makes the act-out task more engaging for children. It also allows us more easily to invite the children to actively participate in the training.

There is also the danger that what seems to be a positive effect of training, might just be a priming effect. Geurts (2003) notes that Smith (1979; 1980) found that children asked to answer quantified questions with *some*, e.g. *Are some cows brown?* then spread more when answering universally quantified questions with *all* like *Are all animals cats?* But when *all* questions were presented first they performed better. This is then in line with Geurts' account of spreading because it suggests that concentrated exposure to weak quantifiers may increase incorrect mapping of strong quantifiers to weak interpretations. But if this interpretation is correct, it also suggests that quantifiers used in training could prime quantifiers in the post-test. To be sure that improvements are unlikely to be caused by priming, we decided to also test the children 5-weeks after training.

The study therefore had four parts. First, all children were tested with a picture verification pre-test to identify which children consistently made overexhaustive spreading errors. Then within one week of the pre-test, children who spread on half or more of the spreading test items participated in the training session. Immediately following the training, the children participated in a short picture verification post-test (with new unique pictures). Finally, five weeks later, children who participated in the training were again tested with a (new) picture verification task.

3. The Training Study

3.1. The Pre-test

65 Dutch children (Mean 6;8, Range 5;4-8;3, 24 girls) took part in the pre-test. Children were tested individually at their school in a quiet area. The pre-test was a Picture Verification Task (PVT) with four experimental conditions. All sentences had a quantified subject DP with the Dutch distributive quantifier *elk* (Eng. *each*[1]) (see Example (4)) paired with one of four pictures. For the *Extra Object* (Fig. 2), *Extra Subject* (Fig. 3) and *1-to-1* (Fig. 4) conditions, variations of a set of pictures were used, all with boys, girls or animals as agents and well-known activities as predicates. The *Extra Object* condition is the target condition which should identify children who make spreading errors. Because of the age of our participants, we don't expect them to make underexhaustive errors so we expect them to reject the *Extra Subject* condition items. The *1-to-1* condition should always be accepted. We also included a set of six *Incorporated Object* items where the object is syntactically incorporated with the verb to see if spreading is less common with these sentences, a prediction of the syntactic accounts. The sentences and corresponding pictures for these items were necessarily different from the other items. See sentence (5) and Figure 5.

(4) Elk meisje wast een hond.
Each girl is washing a dog.

(5) Elk meisje is een thee drinker.
Each girl is a tea-drinker.

Participants saw 40 items in total: 2 practice questions, 8 *Extra Subject* items, 8 *Extra Object* items, 8 *1-to-1 pairing* items, 6 *Incorporated Object* items, and 8 control items that had clear "yes" and "no" answers. *Extra Subject* items, *Extra Object* items and *1-to-1 pairing* items were all balanced across actions and agent types (e.g. *boy, girls, dogs*), while *Incorporated Object* items were the same for

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[1] Dutch has two distributive universal quantifiers, *elke* and *iedere.* Experiments have shown that both have the same meaning (see Spenader & Bosnic, 2018). This meaning is more similar to English *every* than to English *each*.

all participants. All items after the practice questions were presented in unique random orders for each participant.

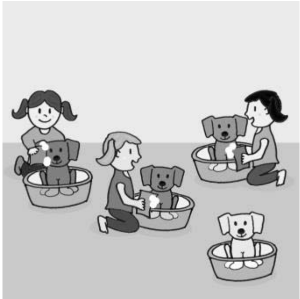

Figure 2. Extra Object

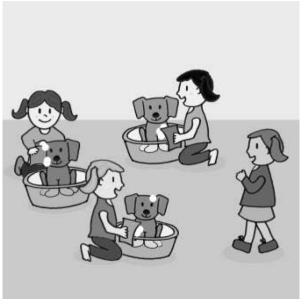

Figure 3. Extra Subject

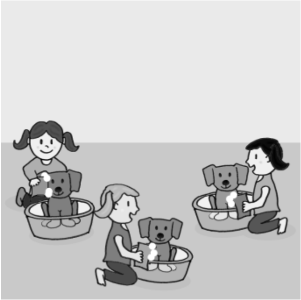

Figure 4. 1-to-1 pairing

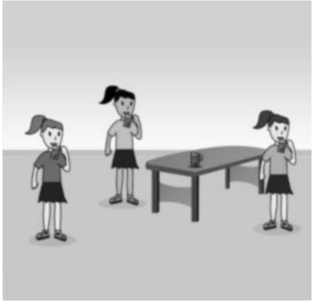

Figure 5. Incorporated Object

3.2. Results Pre-training Test

Table 1 presents the mean acceptance rates for the three relevant conditions. We can see that as a group the children perform worse with the *Extra Object* condition sentences, incorrectly rejecting them 36% of the time, than they do with the *Incorporated Object* condition. Recall that this is predicted by the syntactic accounts that attribute spreading in part to an inability to restrict the quantifier to the correct DP, the DP subject. This is because the NP object is incorporated into the VP and will be less likely to be mistakenly taken as the restrictor. We also can note that almost no children made underexhaustive errors on the *Extra Subject* items, indicating that the children tested know that universal quantifiers require restrictor sets to exhaustively participate in the action.

More relevant is the number of children at each accuracy level, given in Table 2. These results help identify which children make overexhaustive spreading errors. We selected the children who incorrectly rejected *Extra object* trials in at least half of the trials to participate in the training.

Table 1. Mean Acceptance Rates for Pre-training test by Condition

Condition	Mean acceptance	Adults
Extra object	0.64	1
Incorporated	0.73	1
Extra subject	0.10	0

Table 2. Results Pre-test Number of children at each performance level for the two overexhaustive spreading conditions, *Extra Object* and *Incorporated*

Percentage correct	0%	12%-50%	>50%	100%
Extra object	**11**	**14**	13	27
Incorporated object	5	14	10	36

We also used mixed effect logistic regression to analyze these results, with *Condition* treated as a fixed effect and *Item, Participant* and *Age* (as numerical) as random effects. A complex model was only preferred as a simpler model if its AIC value was two or more points lower. The best model retained *Condition, Participant* and *Item.* As expected, 1-to-1 items ($\beta = 5.77$, $Z = 9.32$, $p < .001$) and *Extra Subject* items ($\beta = 2.34$, $Z = 10.48$, $p < .001$) were significantly better than *Extra Object* items. Interestingly, *Incorporated Object* items were also significantly better than *Extra Object* items ($\beta = 0.78$, $Z = 2.3$, $p < .05$), predicted by the syntactic accounts.

3.3. The Training Session

The 25 (M_{age} = 6;6, SE = 0;16, range=5-8, 14 girls) children who made errors in more than half the *Extra Object* trials in the pre-test took part in the training session.

Training took place within one week of the pre-test. The children were trained in a 15 minute, individual, act-out session in a quiet area at their school. Training was indirect, using “Tiger”, a hand puppet. Tiger was presented to the children as a non-native Dutch speaker trying to learn better Dutch. This set-up made it possible to teach the children without actually telling them their responses were incorrect. Children were asked to help “Tiger” learn the word *elke* (*each*). Small physical objects were distributed across laminated paper dolls, using either three boys or three girls. The experimenter then asked

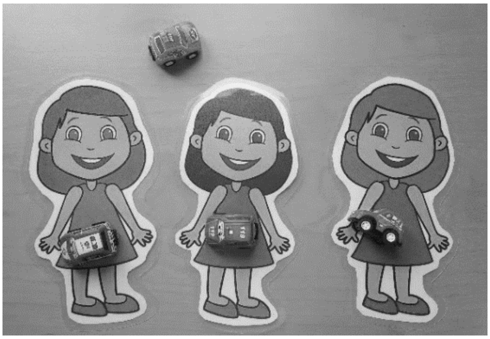

Figure 6. Extra object situation. Each girl has a toy car, but there is also an extra toy car placed above the girls.

Figure 7. Multiple extra objects example Multiple toy cars are placed above the girls.

Tiger about the scenario. Four different situations were used, with: (i) One extra object (see Fig. 6), (ii) Multiple extra objects (Fig. 7), (iii) Two dolls have an object, one doll does not (*Extra subject* condition) (not shown) and (iv) Correct 1-to-1 cases (not shown). The objects were of two types, separate toys (e.g. cars, hamburgers, dice, etc.), or partitionable objects (e.g. cake, lasagna, pie). After laying out the objects in a given formation, the experimenter discussed the layout with Tiger, by first making a statement and asking if it was correct, e.g. (6):

(6) Elk meisje heeft een auto. Klopt dat Tijger?
Each girl has a car. Is that right Tiger?

The first item was always an *Extra Object* item, to check if the children, who did the Pre-Test several days before still made spreading errors.[2] Most children expressed amazement when Tiger was told that the sentence was true.

At the beginning of the training, Tiger consistently made errors with the target *Extra Object* trials. Each time, the experimenter (i) told Tiger he was wrong, emphasizing the need to check that each paper doll has the mentioned object, (ii) emphasized that any additional objects were "extra"/"irrelevant"/"do not participate". This introduced an explicit verification strategy addressing the two possible knowledge gaps from the literature: that the subject NP contributes the restrictor set, and that the scopal set does not have to be exhausted.

Each child was presented with between 8-12 *Extra Object* trials during training, with other conditions mixed in. Each trial used unique objects. During the entire experiment, the child was encouraged to help teach Tiger. Towards the end of the training, after we saw that children could explain correctly to Tiger why spreading responses were incorrect, Tiger begins to also give correct answers, repeating the explanations. After approximately 10 minutes all children were successful, in that they encouraged Tiger to accept *Extra Object* items and could fluently explain why it was correct.

3.4. Post-training Picture Verification Task

Children did the post-training test immediately after the training session. The post-training test was a picture verification task presented on a laptop, similar to the Pre-test but with different pictures and only 12 items, four of each of the three conditions: *Extra Object* items, 4 *Extra Subject* items, and *1-to-1* pairings.

Accuracy levels for *Extra Object* items again differed greatly per child. Table 3 shows how many children were at each performance level. Nine of the children made no spreading errors, four made only one, the remaining 12 children incorrectly rejected half or more of the four *Extra Object* trials.

Table 3. Results post-test Number of children at each accuracy level for *Extra object* trials with picture verification task done immediately after training.

Percentage correct	**0%**	**25%**	**50%**	**75%**	**100%**
Extra object	9	1	2	4	9

We again used mixed effect logistic regression for analysis. The best model retained the fixed effect *Condition* and the random effect of *Participant*. As

[2]One child was not surprised that Tiger was corrected and agreed with the experimenter. However, this same child incorrectly rejected the following *Extra Object* trials, suggesting that the first acceptance was not representative of their knowledge.

expected, *1-to-1* items (β = 5.91, Z = 4.8, p <.001) and *Extra Subject* items (β = 3.97, Z = 5.93, p <.001) were significantly more likely to be interpreted in an adult-like way than *Extra Object* items.

3.5. Results 5-weeks post-training

Five weeks after the training session, the same 25 children who took part in the training took part again in a picture verification task. Different images were used than in the pre-test and post-test. The test included 8 *Extra Object* items, 6 Extra subject items, 8 1-to-1 pairing items, 8 control, and 2 practice questions, for a total of 32 questions.

Table 4. Results 5-weeks post-training test Number of children at each accuracy level for *Extra object* trials with picture verification task done 5-weeks after training.

Percentage correct	0%	≤37.5%	75%-87.5%	100%
Extra object	8	7	3	7

Table 4 shows how many children were at each accuracy level for the *Extra object* condition. Out of the 13 children who no longer made overexhaustive spreading errors in the post-test, 10 still had 75% or greater accuracy 5-weeks later. Seven of these children had perfect scores.

Six of the nine children who made no spreading errors in the post-test still had perfect accuracy 5-weeks later.

There were three children who switched categories. One child, who only got half right in the post-test, improved to have a perfect score on the 5-weeks post training task. Two children with perfect scores in the post-test made errors in the 5-weeks test, one performing close to perfect (mean acceptance rate for *Extra Object* items: 0.875) and one getting all but one item wrong (mean acceptance rate for *Extra Object* items: 0.125).

We again used mixed effect logistic regression for analysis. The best model retained the fixed effect *Condition* and the random effect of *Participant*. As expected, *1-to-1* items (β = 6.5, Z = 6.2, p <.001) and *Extra Subject* items (β = 3.65, Z = 8.51, p <.001) were significantly better than *Extra Object* items.

4. Discussion

Our results suggest that there is a knowledge component involved in children's atypical quantification, and that training this missing knowledge can accelerate children's quantificational development. Training children to identify the subject NP as the restrictor set, and to disregard any additional objects when interpreting universally quantified sentences, helps them achieve adult-like interpretations. Recall that more than half of the children who made spreading errors in the initial pre-test made almost no errors in the post-test given immediately after the training session. The majority of these children (10 out of 13) also retained what they had learned 5-weeks after the training session.

What do these results mean for the specific accounts of spreading discussed in the background? First, our results conflict with accounts that attribute spreading primarily to underdeveloped executive function in children. In a short 10 minutes training, we couldn't have altered children's working memory capacity or their cognitive control. While both these cognitive functions are certainly relevant for language interpretation in general, and probably pay some role in spreading in particular, it seems that some children spread because they do not have adult syntactic and semantic knowledge of quantifiers.

Second, we believe our results are at odds with an interpretation that children simply learned how to do the task, overcoming a pragmatic infelicity in the standard design (cf. Crain et al. 1996). Recall that all children were able to correctly explain to Tiger why a rejection of an *Extra Object* item was wrong, and to explain to Tiger how to use the presented verification strategy to check if a universally quantified sentence was correct. If the children were simply learning to do the task, and parrot the experimenter's explanations, then our results are puzzling. If it is easy to apply task strategies learned in the act-out task to picture verification, why didn't more of the children do well in the picture verification task. If it is difficult to apply task strategies learned in the act-out task then it is remarkable that half the children performed so well when we switched to the picture verification task.

We also think it is unlikely that task-based strategies will be so accessible 5-weeks after training. Further, children's post-training test results are not likely to be due to priming, because most of the same children performed well 5-weeks later.

Instead, we believe our results suggest that spreading errors are due in part to a knowledge gap having to do with restricting the universal quantifier, and that by teaching children an explicit verification strategy, we have helped them learn to interpret universal quantifiers in subject position.

One aspect of our results is surprising. Learning to restrict quantifiers correctly seems to be fairly simple, if ten minutes of training can teach it to half the children. Why then do so many children spread for so long? All the children in our study were from upper middle class native Dutch speaking families. If acquisition depends in part on encountering informative examples in the input, these children have the best chance of exposure, suggesting that informative examples are quite infrequent.

5. Directions for Future Research and Conclusions

We have a number of ideas on how to extend the current research. First, we should include a control group where children are trained with feedback, but without explanations. Arslan et al. (2015) found that even children who were simply given feedback about which interpretation were correct, without any explanation, improved their interpretations of second-order theory of mind questions. It would be interesting to see if this also holds for quantifier interpretation.

Second, the current training focused on teaching children how to correctly restrict quantification in a very direct way. But as suggested in Roeper et al. (2005) experience with sentences where both the subject and the object DPs of simple transitive sentences are quantified may help children realize each quantifier restricts to each DP, e.g.

(7) Every girl read every book.

If exposing children to double quantified sentences like (7) helps them learn not to spread, this would be further evidence that spreading has to do with restricting quantifiers correctly.

Similarly, it would be useful to expand the evaluation done after training. Linguistically, it would be useful to include floated quantifiers in our post-test picture verification task. Results from floated items would tell us if children simply learned to correctly quantify universally quantified subjects when the quantifier was adjacent to its NP complement or if they learned something more general. It would also be useful to include a picture verification spreading task with abstract objects like those first tested by Inhelder and Piaget (1959, e.g. *Is every circle blue?*). Rohlfing (2006) found that children trained in one type of situation performed worse when asked to show knowledge in a more abstract situation. If children still perform well on abstract items it would be more evidence that they learned to restrict quantifiers, and not simply to do the task

In conclusion, with a short training study of 10 minutes we were able to almost entirely eliminate spreading errors in 13 of the 25 children trained. Ten of these children no longer spread 5-weeks after the training.

We certainly do not dismiss the role that task type, attention, cognitive control and processing capacity all play in spreading tasks. However, our results support the view that spreading to some degree is also due to lack of knowledge about how to restrict universal quantifiers, and what sets are relevant in their interpretation. When children are explicitly trained in how to restrict and interpret universal quantifiers, many will begin to give adult-like interpretations.

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