Rules rule in Dutch L1 ordinal comprehension and production

Caitlin Meyer (Corresponding author)

University of Amsterdam

Spuistraat 134

1012VB Amsterdam

The Netherlands

c.m.meyer@uva.nl

+31205254733

Sjef Barbiers

Leiden University

P.N. van Eyckhof 1

2311BV Leiden

The Netherlands

l.c.j.barbiers@hum.leidenuniv.nl

Fred Weerman

University of Amsterdam

Kloveniersburgwal 48

1012CX Amsterdam

The Netherlands

f.p.weerman@uva.nl

Abstract

This article approaches ordinal acquisition in Dutch from the perspective of comprehension as well as production. Novel data from a 'Give Me' and 'Tell me' task (e.g. Wynn 1992, Colomé & Noël 2012) administered to a total of 68 Dutch children (aged 3;3–6;0), show that ordinal comprehension precedes production and that children make use of an ordinal rule from the very beginning: not only do children often produce **drie–de* 'threeth' instead of *der–de* 'third', they also produce **acht–de* rather than *acht–ste* 'eighth', thereby overgeneralizing in cases of root allomorphy and suffix allomorphy. These findings provide the first evidence from production for a rule-based learning pattern and suggest children rely on the structure of ordinals to acquire their meaning, in line with Meyer, Barbiers & Weerman (2016, in press). This makes ordinal acquisition different from cardinal acquisition and typical patterns in the acquisition of derivational morphology.

Keywords: *ordinal numerals, numerical cognition, comprehension, production, L1 acquisition, morphology, Dutch*

1. Introduction

Over the past decades, serious efforts have been made to increase our understanding of how children develop numerical knowledge and number words. This endeavor has focused primarily on cardinal numerals, the development of cardinality, and on how numerical and linguistic knowledge interact. One domain in which this interplay might be particularly visible is the ordinal one: how and when are ordinal numerals like *first, second* and *third* acquired?

Though few studies have attempted to answer this question, one recurrent and perhaps intuitive finding is that ordinals are acquired after cardinals (Colomé & Noël, 2012; Meyer, Barbiers & Weerman, in press; Miller, Major, Shu & Zhang, 2000; Trabandt, Thiel, Sanfelici & Schulz, 2015). This delay could be (partly) motivated by conceptual difficulties, but the available evidence from these studies suggests that linguistic complexity also plays a role: ordinals are more difficult because they are morphologically complex, and the less transparent that complexity is, the more time the learner needs. Exceptions to the regular ordinal formation rule, e.g. irregular *derde* 'third' in Dutch, lead to more comprehension errors than regular forms such as *vierde* 'fourth' and *negende* 'ninth' (Meyer et al., 2016; in press), and learners acquiring a regular ordinal system like Chinese do so faster than learners of a more irregular ordinal list like English (Miller et al., 2000). Though the conclusion might then be that a transparent relationship is (simply) beneficial to ordinal acquisition, Meyer et al. (2016; in press) go one step further, arguing that children use ordinal morphosyntax to acquire ordinal meaning.

However, the data they present for Dutch do not exclude other possible explanations: could it not be, for example, that children learn ordinals in a tiered and (at least initially) purely lexical fashion, similar to the way children acquire cardinals? The cross-linguistic differences in ordinal acquisition mentioned above could then be explained on the basis of

differences in the speed of cardinal acquisition. Such a lexical approach would also be more in line with what has been reported for the acquisition of derivational morphology: usually, children acquire complex forms as wholes and only decompose them into separate morphemes after having collected sufficient evidence for their complexity (Clark, 2014). Meyer et al.'s claim for ordinals, on the other hand, is that children recognize and use the complexity to understand the meaning of the whole. Put differently, the typically observed pattern entails learning 'from the outside in', whereas the ordinal pattern Meyer et al. drive at entails acquisition 'from the inside out'. The evidence for actual rule-based learning is somewhat limited, though, in part because the authors only tested comprehension. Whether the patterns found in comprehension are mirrored in production, and what this says about the rule(s) children follow as they acquire these synthetic ordinal forms (if there are indeed any rules to speak of at this early stage), has yet to be investigated.

The present study is the first to discuss ordinal production data, and compares the comprehension and production of ordinal numerals in Dutch monolingual children. It thereby contributes to our understanding of numerical development more generally and ordinal acquisition in particular. Our data confirm that ordinals are not simply acquired lexically and provide insight into how children develop the ordinal formation rule. We first go into what is known about ordinal acquisition, and what evidence there is to suggest that transparency plays a key role. Section 3 makes our hypotheses and predictions explicit. We describe the comprehension and production task (both in the spirit of Wynn's 1992 'Give-a-Number' task) we used to test these hypotheses in section 4 and discuss the results of these tasks in sections 5 and 6, highlighting the differences and similarities between the two along the way. Section 7 concludes: rules rule in ordinal acquisition.

2. Ordinal acquisition and transparency

As mentioned in the introduction, little systematic evidence pertaining to the acquisition of ordinals exists. However, there is some work that sheds light on this process in a variety of languages: English, (Fischer & Beckey, 1990; Miller et al., 2000), Chinese (Miller et al., 2000), French (Colomé & Noël, 2012), German (Trabandt et al., 2015) and most recently Dutch (Meyer et al., 2016, in press). Taken together, these studies suggest that while there are language-specific effects that play a role, there are also some more general tendencies that apply. Since those tendencies have to do with the timing and pattern of ordinal acquisition relative to cardinal acquisition, it is important to briefly discuss cardinal acquisition first.

2.1 A brief note on cardinal development

Cardinal acquisition has been shown to proceed through a stepwise pattern in which children slowly grasp the meanings of the first four cardinals one by one (e.g. Le Corre & Carey, 2007). At first, children may be able to recite a count list (although not necessarily an adult-like one from the start) and understand that cardinals refer to a numerosity, though they may not know which one. These children are referred to as 'pre-knowers' and are typically around two years old at this point. The first numeral to which they assign an exact interpretation is *one*. They then know that *one* means exactly one, and that other numerals must be more than one. Such a '1-knower' will be able to give you, for example, one button if you ask the child for *one button*, but when asked for e.g. *two buttons* the child could give you any number of buttons higher than one. Next the learner acquires the meaning of *two*. A 2-knower can give the appropriate number when asked for *one* or *two*, but when asked for *three* may give you three, four, or any other number higher than two. Similarly, 3-knowers have exact knowledge of cardinals up to and including *three*, and it is at this point that they should realize that numerals refer to discontinuous quantities rather than, say, individuals and pairs, for *one* and

two (Sarnecka, 2015). In the next stage, children develop exact understanding of *four*, becoming 4-knowers. Collectively, these knowers are known as 'subset-knowers', as they know a subset of the cardinals they can recite in a list (Le Corre et al., 2006).

The next stage in cardinal acquisition is quite a step, as this is when children are able to infer the meanings of all the other cardinals in their count list and become fully competent counters, or 'cardinal principle knowers' (CP-knowers). At this point, children know at least three counting principles (see also Gelman & Gallistel, 1978): the one-to-one correspondence principle (every cardinal belongs to one counted item), the stable order principle (the count list has a strict order), and the cardinal principle (the numerosity of the set is equal to the last number counted). When asked *how many* there are, CP-knowers count to determine the answer and repeat the last-named numeral. Children may reach this stage anywhere between their third birthday and some months after they turn four. Though the start and duration of each stage varies considerably, this slow and sequential pattern of development is well-documented and has been shown to hold for learners from various linguistic backgrounds (e.g. Almoammer et al., 2013; Barner et al., 2009; Condry & Spelke, 2008; Huang et al., 2010; Le Corre & Carey, 2007 ; Le Corre et al., 2016; Meyer et al., in press; Piantadosi et al., 2014; Sarnecka, 2015; Sarnecka et al., 2007; Wynn, 1992). We refer the reader to Sarnecka (2015) for a detailed and recent overview of children's development of numerical knowledge.

2.2 Ordinal development

The cardinal acquisition pattern is immediately relevant to the ordinal one, not only on an empirical level (as mentioned above), but also on a conceptual one: the one-to-one correspondence principle and the stable order principle are not only necessary to determine *how many* in a set (i.e. cardinality) but also *which one* in a line or progression (i.e. ordinality). The conceptual difference between answering those two questions is that the cardinality principle needed in the first situation is exchanged for the ordinality principle in the latter: the

last count then represents not the cardinality of the set, but the ordinality of that individual item. Meyer et al. (2016) initially speculate that it should not be more difficult for children to learn to apply the cardinality principle before the ordinality principle, reasoning that picking out an individual from a set (ordinality) is not conceptually more complex than representing the entire set (cardinality).

However, what they and others observe in acquisition is that ordinals are in fact acquired later than cardinals. Children of various ages can count further using cardinals (Miller et al., 2000) and kindergarteners perform better on cardinal comprehension tasks than on ordinal ones (Fischer & Beckey, 1990; Colomé & Noël, 2012; Meyer et al., 2016/in press). Moreover, from pretest data described in Matthei (1982) and Hamburger & Crain (1984) we can conclude that at the age at which most children should be fully competent counters, roughly one in five children still fails to demonstrate knowledge of *second* and *third*. Meyer et al.'s (in press) 'Give Me' type comprehension task (cf. Wynn, 1992; Colomé & Noël 2012) directly shows that at least some cardinal knowledge is in place before ordinal acquisition begins. Children who have yet to acquire the first four cardinals also fail to grasp the meaning of (any) ordinals; such pre-to-3-knowers are only able to demonstrate that ordinals refer to individuals, not sets. In other words, when asked for *the fourth,* these children grab only one item (and not, for example, four) though they do select the incorrect one. These difficulties do not suddenly disappear when children acquire the cardinal principle, either, as even children who can be classified as CP-knowers often have difficulty on the ordinal trials in this study.

Cardinal and ordinal acquisition not only differ with respect to timing, but also with respect to the pattern that we observe. Whereas lower cardinals are acquired in a tiered or stepwise pattern (i.e. children who have mastered *four* also have an exact understanding of *three*), Meyer et al. (in press) claim that regular ordinals are acquired at once (at least

conceptually – while some children have difficulty with high ordinal *achtste* 'eighth' they argue this is due to performance issues) and irregular ordinals follow later. They find that Dutch 4-knowers and CP-knowers were able to find at least the *eerste* 'first', and usually also the *tweede* 'second, lit: two–th' and *vierde* 'fourth', while comprehension of the irregular form *derde* 'third' seemed to develop later, in some children even after (regular) higher ordinals like *achtste* 'eighth' and *negende* 'ninth'. The acquisition pattern they describe can be summarized as follows:

(i) Children use morphosyntactic cues (such as the fact that ordinals combine with singular nouns, whereas most cardinals combine with plurals) to discover that ordinals refer to individuals, not sets.

(ii) Children, when they are at least 4-knowers, acquire *eerste* 'first' first. This form does not require true counting competence and has been shown to be a regular superlative (rather than an ordinal) in Dutch (Barbiers 2007).[1] Moreover, *eerste* is roughly 50% more frequent than *tweede* 'second' through *twintigste* 'twentieth' combined.

(iii) Children acquire the ordinal formation rule (informally: cardinal + suffix = ordinal), as CP-knowers. This leads to (near) ceiling performance on at least low, regular ordinals like *tweede* 'second, lit: two–th' and *vierde* 'fourth'.

(iv) Performance on higher, regular ordinals depends on extra-linguistic factors (the further one has to count and maintain one-to-one correspondence, the more demanding the task

[1] Though *eerste* ' first' is not strictly speaking an ordinal, we are including it in the developmental pathway for ordinals because it does fulfill that function in practice. Note that the claim is not that children extrapolate linguistic knowledge pertaining to *eerste* 'first' to other ordinals; the acquisition of *eerste* simply precedes that of ordinals due to its frequency and relative simplicity (no counting is involved).

becomes) and is by definition limited to CP-knowers only, since children who cannot count beyond *four* cannot be expected to count to higher ordinals either.

(v) Performance on irregular *derde* 'third' follows at some point after acquisition of the rule. Note that this might be before or after performance on higher ordinals improves.

Meyer et al. (in press) argue that children's failure to comprehend irregular *derde* 'third' while being able to find other (higher) ordinals shows that children do not store individual ordinals lexically (at least not with an interpretable meaning), but derive them via a morphological rule. The authors hypothesize that children acquire ordinals via rules from the very beginning, first applying the regular counting principles to the cardinal root, and then adding on the semantic contribution of the ordinal suffix (namely, to pick out an individual, rather than denote the cardinality of a set). Such a strategy fails in irregular cases, where the root allomorph is not recognized as such. (Though the authors do not say so literally, it appears children recognize *der* in *der–de* should be a cardinal, but do not know to which cardinality it refers; children would sometimes look at their fingers and ask *wat is der* 'what is *der*' or count out loud and say that *der* is not there).

This stance is not exactly uncontroversial, as it goes against the typical patterns in acquiring morphology, both derivational and inflectional. Children are known to be 'little inflection machines', demonstrating knowledge of inflectional elements from the earliest stages of production, i.e. from around 18 months on (Wexler, 1998, p. 43), especially if the inflections are regular and salient (see Polišenská, 2010 for discussion). By the age of three, children have developed clear knowledge of number marking on nouns, and number and person on verbs, though their production is far from perfect (see e.g. Polišenská, 2010; Van Wijk, 2007; Wood, Kouider & Carey, 2009). The most persistent errors occur in irregular forms, and are typically overgeneralization errors that follow a so-called change for the worse

or U-shaped pattern of development. The classic example is the production of English past tense: children may initially say *went* correctly, but **goed* then also temporarily occurs in their production after acquiring the *–ed* rule. Ultimately, this overgeneralized form disappears (e.g. Marcus, Pinker, Ullman, Hollander, Rosen & Xu, 1992; Pinker, 1999). Crucially, inflectional morphology is acquired relatively early on, and in a rule-based fashion.

By contrast, derivation is not as well-studied as inflection in acquisition, but evidence from adults suggests that storage often beats computation in adults, for whom it has been claimed that derived forms are more likely to be lexicalized because the affix changes the word class, whereas regular inflections are more likely to be processed combinatorially (e.g. Clahsen, 2006; Leminen, Leminen, Kujala & Shtyrov, 2012). This makes it unsurprising that the limited work on child language does not seem to provide evidence for a rule-based approach or U-shape in the acquisition of derivation. Quite the contrary: the typical pattern involves children learning individual items lexically, only to generalize over these examples and form a productive rule after they have accumulated sufficient evidence for their morphological complexity (Clark, 2014). Put differently, whereas children typically learn complex forms as a whole before being able to decompose them into separate morphemes, the ordinal situation involves children using the parts to arrive at the meaning of the whole. This process comes sooner for some affixes than for others; while agentive *–er* in English is productive in three-year-olds, most derivational affixes are acquired during elementary school and the timing depends on the identifiability and transparency of both the root and the affix, as well as on productivity (Clark, 2014). For example, allomorphs of the Dutch diminutive are acquired between the ages of five and nine (Boersma, Rispens, Weerman & Baker, under review), depending on the phonological complexity of the root and frequency of the affix. All in all, this makes Meyer et al.'s claim (as they also admit) quite a strong claim,

which requires further investigation, preferably with support from production data, which has yet to be discussed.

3. Hypotheses and predictions

The present study aims to address some open issues that would further test the hypothesis put forward in Meyer et al. (in press): are ordinals in fact acquired in a rule-based fashion and what might the nature of this rule be? We look at different types of ordinals, not only in comprehension, but also in production, which allows us to investigate to what extent difficulties in comprehension are also reflected in production. Following Meyer et al. (in press), we focus on Dutch. Though we have already discussed some relevant properties of the Dutch ordinal system above, Table 1 provides an overview of the first twenty cardinals and ordinals in Dutch, including their absolute frequencies in the *Corpus Gesproken Nederlands* 'Spoken Dutch Corpus'(Oostdijk, 2000).[2] The CGN contains roughly 9 million words in 1000 hours of speech files from the Netherlands and Flanders; the frequencies given represent absolute occurrences per million words.

#	Cardinal	Ordinal	Frequency	#	Cardinal	Ordinal	Frequency
1	één	eer–ste	1214.11	**11**	elf	elf–de	7.78
2	twee	twee–de	387.33	**12**	twaalf	twaalf–de	9.67
3	drie	der–de	151.44	**13**	der–tien	der–tien–de	8.22
4	vier	vier–de	69.89	**14**	veer–tien	veer–tien–de	8.56
5	vijf	vijf–de	40.22	**15**	vijf–tien	vijf–tien–de	8.44
6	zes	zes–de	37.00	**16**	zes–tien	zes–tien–de	11.22

[2]Ordinals hardly ever occurred in the available Dutch corpora in CHILDES (MacWhinney 2000), both in child-directed speech and even less in child production, which is why we are reporting CGN data.

7	zeven	zeven–de	17.00	**17**	zeven–tien	zeven–tien–de	11.22
8	acht	acht–ste	10.78	**18**	acht–tien	acht–tien–de	11.78
9	negen	negen–de	9.67	**19**	negen–tien	negen–tien–de	14.56
10	tien	tien–de	17.89	**20**	twin–tig	twin–tig–ste	14.67

Table 1: Cardinal and ordinal formation in Standard Dutch. Frequencies taken from Meyer et al. (in press).

As in English, ordinals in Standard Dutch are derived by adding a suffix to the rightmost part of the cardinal. For most ordinals ending in a numeral under 20 (low ordinals, but also e.g. *tweehonderddertiende* 'two hundred thirteenth'), this suffix is *–de*; all other ordinals are formed with *–ste*. There are three exceptions that we discussed in passing earlier: *eerste* 'first', *derde* 'third' and *achtste* 'eighth'. Again, we take *eerste* 'first' to be a superlative, and not a product of root allomorphy plus the higher ordinal suffix *–ste* (see Barbiers, 2007 for the relevant observations and arguments). The other two cases are true irregularities: *derde* (not **drie–de*) is a case of root allomorphy, while *achtste* takes *–ste* (not **acht–de*).

Obviously, the minimal expectation of the present study is to replicate (where applicable) the findings in Meyer et al. (in press). The further goals are to answer the questions that follow from earlier work, the most urgent of which is to what extent a rule really is at play, or whether there are other conceptual or frequency difficulties that influence children's behavior. One way to test this is to include the regularized yet ungrammatical form **driede* 'threeth' in the comprehension task. If children perceive the morphological structure of ordinals, then the difficulty attested in Meyer et al. (in press) for *derde* 'third' should not appear in the regularized form *driede* 'threeth', despite its ungrammaticality and its absence from the input. Moreover, if children are actively (productively) using a rule, we also expect this regularized form to arise in children's production. In other words, children who are unable to comprehend *derde* but do understand the regular neighbors *tweede* 'second' and *vierde* 'fourth' are expected to produce the regularized form **driede* 'three–th'. If they do

not, any effects found in the comprehension task may simply reflect some (task-specific) answering strategy. Obviously, we expect that children who cannot find the *derde* 'third' item in a comprehension setting, will not use that form when asked to describe the third item in line in an elicited production setting.

We also expect to see some sort of rule effect in the case of *achtste* 'eighth', and the use of the suffixes children use there and elsewhere. It is possible for children to be lenient or 'sloppy' about their rule in comprehension situations, especially in a test setting such as in the 'Give a number': the task repeatedly asks for different numerals, and so children may be able to infer the meaning of *achtste* 'eighth' within this particular context. However, their production might reveal more. The form **achtde* would provide direct evidence for a rule in which only *–de* is considered an ordinal suffix (at least for lower ordinals), whereas *achtste* could either be lexically stored, or the product of a rule in which *–ste* (also) plays a role (e.g. where the rule specifies for which root each suffix applies).

One might be inclined to entertain a similar type of reasoning for *eerste* 'first' as for *derde* 'third' and *achtste* 'eighth', arguing that a form like **eende* 'one–th' or **eenste* 'one–est' may appear in production. However, Meyer et al. only mention anecdotal evidence for **driede*, not for regularized ordinal alternatives to *eerste* 'first'. According to Barbiers (2007), the feature composition of *één* 'one' is incompatible with regular ordinal formation in Dutch, but to what extent the superlative status of *eerste* affects any possible interpretation or production of **eende* 'one–th'or **een–ste* 'one–st' (which entails a category change) would require separate study in and of itself, making it difficult to formulate precise predictions for *eerste* and its regularized counterparts at this time. Nevertheless, one possible outcome would be clear: if children are able to interpret **eende* 'one–th' or **eenste* 'one–st' as the first in line, this means they are decomposing this form on the spot: because these forms are

impossible in adult Dutch, they are absent from the input, and thus their meaning could not be determined in any other way.

From the above, the reader may conclude that we are pitting two potential challenges against each other: root allomorphy (as in *derde* 'third') and suffix allomorphy (as with *achtste* 'eighth'). Note that the challenges of each of these forms are different in comprehension and production. In comprehension, it may be easier to 'ignore' the irregularities in suffix as long as the relationship with the cardinal base is transparent (i.e. maybe *achtste* is easier than *derde*) whereas in production, the difference in suffix may be less salient than the root allomorphy in *derde*, which is also much more frequently encountered. Hence, it may be that the challenge in *derde* is overcome more quickly in production than the irregularity of *achtste*.

In short, our study is set up to test whether children acquire ordinals in a rule-based fashion along the lines of Meyer et al. (in press), adding insight from production data. Ordinals should be acquired after children acquire cardinals, and after the superlative *eerste* 'first'. Children should learn regular forms simultaneously, though higher ordinals may follow later for non-linguistic reasons. But the key focus will be on irregular forms: we expect to find children who have difficulty comprehending and/or producing the irregular form *derde* 'third' (i.e. using **driede* instead), and difficulty producing *achtste* 'eighth' (i.e. saying **achtde* instead). More generally, we expect children to comprehend the necessary forms before they can produce them.

4. Method

The studies on cardinal and ordinal acquisition discussed above all make use of some variation of the 'Give-a-Number'/'Give me' paradigm (Wynn, 1992), while Colomé & Noël (2012) adapted this for eliciting production data as well ('Tell me'). We took a similar

approach, testing all children on both comprehension (cardinals and ordinals) and production (ordinals only).

4.1 Participants

A total of 68 typically-developing monolingual Dutch children (37 boys, 31 girls; ages: 39–72 months, M=58.90, SD=8.53) could be included in the results. We excluded an additional 15 children (11 male, 4 female; ages: 37–72 months, M=45.13, SD=10.36) because they did not complete the entire task. The excluded children (of whom 11 were under the age of four) were typically unwilling or unable to provide any (relevant) responses in the first session, which tested production.

4.2 Materials and procedure

We made use of the materials developed and discussed by Meyer et al. (in press), adapting them such that they could be used to test both comprehension and production in two separate sessions. The production task focused on ordinals only, testing *eerste* 'first' through *vierde* 'fourth', *zesde* 'sixth', *achtste* 'eighth' and *negende* 'ninth', plus the indefinite ordinal *laatste* 'last'.[3] Each ordinal was elicited three times, leading to a total of 24 items in this session. The comprehension task, which we expected to be easier and faster to administer, included the ordinals tested in production, their corresponding cardinals (to assess a child's knower-level), plus the ungrammatical but regular forms **eende* 'oneth', **eenste* 'onest', and **driede* 'threeth'. Here, too, each numeral was tested three times, bringing the total session to 54

[3] Note that we did not test more ordinals because it would have made the test too long, especially for the comprehension session. We chose the first four ordinals to be able to watch for stepwise patterns (as with cardinals), *achtste* 'eighth' because it is irregular, *negende* 'ninth' as its regular neighbor, and *zesde* 'sixth' as an intermediate place between low and high. Put differently, we used an improved/elaborated version of the original Meyer et al. (2016) list.

items. We administered the production sessions first to ensure the comprehension items could be of no influence on the production items (i.e. so children would not be 'inspired' by the comprehension session). Sessions were administered within one week of each other.

At the beginning of the session, the experimenter familiarized the child with the procedure and the materials, by means of a short introductory story in which a monkey puppet named Jaap is going on an exciting trip. The story describes how all of Jaap's things (laminated cards with images of everyday objects and animals on them) are so eager to join him, that they are getting in line to jump into his suitcases (two metal toy suitcases). The monkey knows he will not be able to bring everything, so the child is asked to help him pack the correct items from the line into the suitcases. In the production session, the monkey knows what he wants to bring but doesn't know how to say it, and so the child 'teaches' the monkey how to ask for the correct items by completing the answer to a question, such as in (1). The experimenter urged the child to count out loud and use his or her finger while counting in order to reduce the number of errors caused by imperfect counting. Children were also allowed to recount ("check and make sure") as often as they wanted. Children who simply counted and repeated the last count (e.g. *een, twee, drie, vier – vier* 'one, two three, four – four') received an extra prompt: *Dus hij is de…?* 'So he is the…?' Note that the stimulus and the extra prompt included a definite determiner, making a response with an analytic ordinal (e.g. *beer drie* 'bear (number) three') ungrammatical (cf. Colomé & Noël 2012 for the use of analytic ordinals in French-speaking children).

(1) De aap zegt dat deze beer mee mag. Welke beer is dit/Op welke plek staat deze beer? (Op de/ Hij is de…)

The monkey says that this bear with may. Which bear is this/On which place stands this bear? (On the/He is the…)

The monkey says that this bear gets to come. Which bear is this?/Which place is this bear in? (The…)

In the comprehension session, the monkey puppet thinks he has learned how to ask for the right things and the child's job is to pack what the puppet asks for, such as *één camera* 'one camera' or *het derde konijn* 'the third bunny'. Literal examples of stimuli are given in (2) and (3) for cardinals and ordinals, respectively. In an effort to keep the game-play natural, formulaic variation did occur, but typical comprehension stimuli offered the numeral as part of a full subject DP. When necessary, the numeral was repeated with either a noun (in the case of cardinals, e.g. *negen ballonnen* 'nine balloons') and/or a definite article (in the case of ordinals, e.g. *de tweede (slee)* 'the second sled'[4]). Children were allowed to 'count and make sure' their responses were correct.

(2) Er mogen acht stiften mee. Kun je acht stiften (tellen en) inpakken voor Jaap?
There may.pl eight markers with. Can you eight markers (count and) pack for Jaap?
'Eight markers get to come. Can you (count and) pack eight markers for Jaap?'

(3) Jaap zegt dat de zesde jas mee mag. Kun je de zesde jas (vinden en) inpakken voor de aap?
Jaap says that the sixth coat with may. Can you the sixth coat (find and) pack for the monkey?

[4] Note that N-ellipsis in the ordinal case should not be an issue. For one, the child always heard the full DP in the initial stimulus. For another, N-ellipsis occurs naturally in child speech from at least 1;8 on, using licensors such as (but not limited to) cardinals, quantifiers superlatives and *eerste* 'first' (Sleeman & Hulk, 2013).

Jaap says the the sixth coat gets to come. Can you (find and) pack the sixth coat for the monkey?

The pictures we used for ordinal items (both sessions) had clear fronts or faces in order to emphasize the direction of the line, and all items in that line were identical (so the child could not select an object on the basis of any other distinguishable property). The number of items in line depended on the cardinal or ordinal in question: the lowest numeral trials (*one, two, first* and *second*) all occurred with four cards in line; numerals *three, four, third* and *fourth* with six cards, and the higher numeral conditions consisted of ten cards. We presented items in one of eight (comprehension) or two (production) pseudo-random orders within each session, which we counterbalanced between participants. Both sessions started with two practice items (in which children had to find or name a certain object *vooraan* 'at the front' and *achteraan* 'at the back' of the line), and ended with a counting session, in which children were asked (to try) to recite the cardinal and then ordinal count list to *thirty* (*thirtieth*). Children were allowed to use the cards to perform these counting tasks.

Before looking at ordinal knowledge, we first determined the cardinal knower-level for each child using the knower-level estimation tool provided by Lee & Sarnecka (2010a,b) and the criteria described in e.g. Le Corre & Carey (2007). According to these criteria, children had to provide the correct number of cards for a given numeral at least two out of three times when asked for that numeral, and provide that number of cards no more than once in response to a different numeral. Applying the criteria and the tool yielded the same outcome in all but two instances, where we opted to give the child the benefit of the doubt. For determining

children's ordinal knowledge, we followed Meyer et al. (in press) in that we only took children's correct responses into account.[5]

5. Comprehension

Table 2 displays the ages of the children at each cardinal knower-level and their group performance on the counting task, for which the highest count of the two sessions was used for each child. Two CP-knowers (children who mastered the cardinal principle) did not want to perform the counting task; there is no counting data available for them. All but one child recited a count list higher than ten (which was the maximum number of cards on the table for any given trial).

Levels	*n*	Age			Count List		
		Range	*Mean*	*SD*	*Range*	*Mean*	*SD*
2-knowers	2	3;3–4;0 (39–48)	43.5	6.36	10–16	13	4.24
4-knowers	6	4;0–5;10 (48–70)	55.67	7.61	17–20	18.5	1.05
CP-knowers	60	3;6–6;0 (42–72)	59.73	8.19	6–30	26.05	5.77

Table 2: Overview of the ages and count lists per cardinal knower-level attested in our sample. Age ranges and means are given in years (year;month) and months, the SDs in months only.

These data are in line with what is described in Meyer et al. (in press), who also lacked 3-knowers and found similar mean ages among 2-,4- and CP-knowers (namely 44.5, 52.1 and

[5] Meyer et al. (in press) explain that since the acquisition pattern of ordinals does not appear to be tiered in the way cardinal acquisition is, it is difficult to determine what an error means for the ordinal the child provided incorrectly and whether (and how) such an error should be weighted. Unlike the cardinal situation, giving three items when asked for *six* entails the child does not understand either numeral (and all numerals in between), whereas giving the sixth item when asked for the *third* does not imply the child will not understand *fourth, fifth* or even *sixth* – the only clear problem is *third*.

59.6 months, respectively, cf. their Table 3). Note, however, that the overall mean age in our sample is higher: 59.5 months (SD=8.1) versus 52.4 months (SD=10.6).[6]

5.1 Results

We excluded three children from further analysis on the basis of their performance: both 2-knowers and a 4-knower. One of the 2-knowers and one of the 4-knowers in our sample lacked specific ordinal knowledge altogether. While these children did only give one card in response to ordinal stimuli, indicating that they were at least not assigning a cardinal interpretation to the ordinals, the 2-knower appeared to always pick a random card while the 4-knower always selected the first card (see the first-bias reported in Meyer et al. in press). We also excluded the other child we categorized as a 2-knower from the analysis: this child often gave ordinal responses to cardinal trials (e.g. packing just the fourth card when asked for four), in addition to ordinal responses on ordinal trials (passing on all ordinal items except those for *derde* 'third' and 'eighth').[7]

The remaining 65 4-knowers and CP-knowers provided correct responses to at least some of the ordinals we tested. Before discussing the distribution of correct responses, however, it is worth noting what kind of errors we encountered. As in Meyer et al. (in press), a cardinal answer in response to an ordinal trial (e.g. giving four cards when asked for the fourth) was extremely rare, occurring on only five occasions (out of over 3500 trials in our dataset). Instead, nearly all errors were cases where children selected just one card from the line in response to an ordinal. In other words: they selected the incorrect card, but not an

[6] Though we did test younger children, many of them were excluded for not being able to perform on the production task.

[7] This behavior may indicate an underestimation of this child's knowledge of cardinals, and may indicate a task effect (i.e. the similarity of the different types of trials may have influenced this participant's performance) but we have no other means at our disposal to determine her knowledge otherwise.

incorrect number of cards. Errors in ordinal comprehension were generally rare, as Table 3 and Figure 1 show.

Ordinal		4-knowers			CP-knowers		
		M	***SD***	***SE***	***M***	***SD***	***SE***
1st	eerste	0.933	0.258	0.067	1	0	0
2nd	tweede	0.867	0.351	0.091	0.983	0.128	0.010
3rd	derde	0.4	0.507	0.131	0.694	0.462	0.034
4th	vierde	0.667	0.488	0.126	0.983	0.128	0.010
6th	zesde	0.4	0.507	0.131	0.978	0.148	0.011
8th	achtste	0.267	0.458	0.118	0.928	0.260	0.019
9th	negende	0.267	0.458	0.118	0.972	0.165	0.012
*three–th	*driede	0.8	0.414	0.107	0.994	0.075	0.006
*one–th	*eende	0.733	0.458	0.118	0.956	0.207	0.015
*one–st	*eenste	0.8	0.414	0.107	0.933	0.250	0.019
last	laatste	0.867	0.352	0.091	0.956	0.207	0.015

Table 3: Mean proportion of correct responses by knower-level

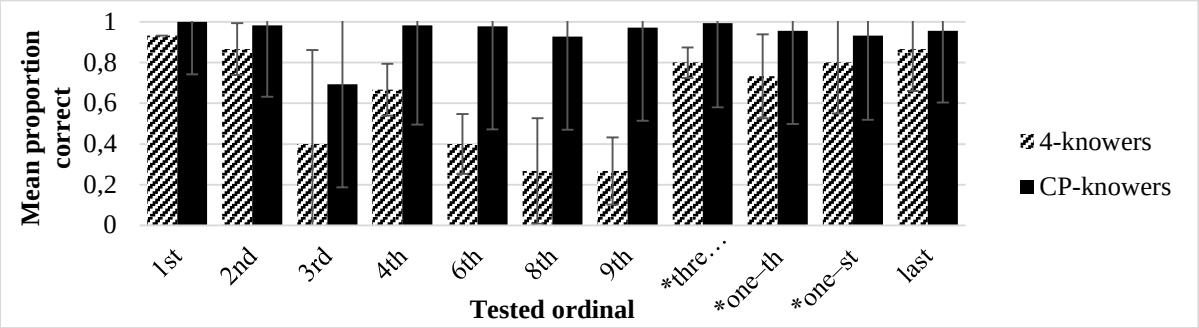

Figure 1: Mean proportion of correct responses by knower-level; error bars represent one SD from the mean.

Figure 1 shows that CP-knowers nearly always provide correct responses on ordinal comprehension items. Wilcoxon signed ranks tests reveal a significant difference between the

irregular form *derde* 'third' and *tweede* (Z=-4.125, p<0.001) and *derde* and *vierde* (Z=-4.128, p<0.001), but not between *driede* and *tweede* or *vierde*. In addition, all 18 CP-knowers who cannot find the *derde* 'third' (30%) are able to find the *driede* 'threeth'. Irregular *achtste* 'eighth' differs from *derde* 'third' (Z=-3.430, p=001) and *zesde* 'sixth' (Z=-2.310, p=0.021) but not from *negende* 'ninth', nor do *zesde* and *negende* differ significantly. We also see that CP-knowers do well on indefinite ordinal *laatste* 'last' and the ungrammatical yet regularized trials. Performance on regularized ordinals for *eerste* 'first' (*eende* 'oneth', with the ordinal suffix *–de*, and *eenste* 'onest', with the suffix for superlatives and ordinals *–ste*) are at ceiling. The 4-knowers have difficulty across the board, with none of the ordinal pairs having significantly different mean proportions of correct responses, although one would expect (perhaps with a larger sample) that *derde* 'third' and higher ordinals would evoke significantly lower scores.

We now need to see to what extent different factors influence the performance described above. We used R (R Core Team 2016) and *lme4* (Bates et al., 2015) to fit a generalized linear mixed-effects logistic regression model to these data described above, minus those items that we included above to be complete, but strictly speaking do not fit into an ordinal analysis, namely those forms that are considered superlatives (*eerste* and its regularized counterparts **eende*, and **eenste*, as well as *laatste*). In other words, we tested all regular ordinals *tweede, derde, vierde, zesde, achtste, negende* and **driede* ('second'–'fourth', 'sixth', 'eighth', 'ninth' and 'threeth').

Our statistical analysis follows the procedure described in Meyer et al. (in press): we ran two model comparisons to determine whether age or knower-level was a better predictor of performance on ordinal comprehension, and to determine whether the place in the ordinal list better explains the data than morphological irregularity. We included participant as a random intercept with random slopes for ordinal as a continuous factor in all models, and the

dependent variable in all models was whether a child's response was correct or incorrect.[8] Though we included the same fixed factors, some were treated slightly differently: (i) we treat knower-level as a categorical factor as per Meyer et al.'s suggestion (they treat it as continuous, but note that it would be better to treat it as categorical with more and/or more focused data), and (ii) we coded *achtste* 'eighth' as irregular (Meyer et al. treat it as regular; their data left no room for testing the effect of *–ste*, since *achtste* was effectively the only higher ordinal in the set) within the factor regularity.[9] Continuous factors were centered; categorical factors were coded with explicit contrasts before analysis. No outliers other than those described above were removed.

Like Meyer et al. (in press), we added the factors age and knower-level to our model one by one. We first fit a model in which we included the regularity of the ordinal numeral (i.e. whether the ordinal numeral was irregular, as in the case of *derde* 'third', or regular, as for e.g. *zesde* 'sixth') and place in the ordinal count list (continuous, as treating this factor as categorical leads to rank deficiency) as well as knower-level (categorical) as fixed factors, plus interactions between knower-level on the one hand, and ordinality and regularity on the other. We then compared this model to one in which knower-level was replaced by age (for which M = 59.5 months, SD= 8.1 months, range = 42–72 months). Although age was a significant factor within the second model ($z = 2.830$, $p=0.0047$), the AIC and BIC were lower for the first model (AIC: 493.67 vs. 599.12, BIC: 540.64 vs 677.40, respectively). We

[8] Including ordinal as a categorical factor led to convergence errors. We opted to simplify the model rather than eliminate the random slopes completely.

[9] Note that it is not possible to tease apart the effects of root allomorphy and suffix allomorphy directly. While we did test a regularized counterpart for *derde* 'third'(namely **driede*), we did not test a regularized counterpart for *achtste* 'eighth'. Moreover, these properties do not occur anywhere besides *derde* and *achtste*, and so these factors cannot be analyzed apart from the place in the ordinal count list.

therefore conclude that, as in Meyer et al. (in press), knower-level better predicts ordinal comprehension than age.

We then compared the first model to one in which regularity was excluded and ordinal was a categorical (rather than continuous) variable. The prediction is then that though this new model has more parameters and thus should explain more variance, most of the variance is already explained by the existing model. The comparison reveals, as in Meyer et al. (in press) that this latter model (without regularity as a fixed factor) has a higher AIC (584.89) and BIC (731.02). We therefore maintain the model as initially constructed. Table 4 describes the results of this final model.

Predictors	**Estimate**	**CI**	**SE β**	***z***	***p***
Intercept	2.731	1.27 – 4.19	0.745	3.665	0.0002
Ordinal	-0.050	-0.43 – 0.33	0.195	-0.256	0.7981
(Ir)regularity	-3.155	-4.03 – -2.28	0.445	-7.097	<0.0001
Knower-level	5.560	2.74 – 8.38	1.437	3.869	0.0001
Ordinal*Knower-level	1.074	0.35 – 1.80	0.368	2.920	0.0035
Regularity*Knower-level	-2.411	-4.08 – -0.74	0.852	-2.830	0.0047

Table 4: Result summary for correct responses on 2nd, 3rd, **driede*, 4th, 6th, 8th and 9th: β coefficient estimates, confidence intervals, standard errors, associated Wald's z-score and significance level (p) for all predictors in the analysis.

Overall, the model reveals main effects of the (ir)regularity of the ordinal form, such that irregular ordinals led to a lower probability of correct comprehension, and of knower-level, such that CP-knowers were more likely to provide a correct response. There was no significant main effect of ordinal: as the ordinal list progresses, the likelihood of a correct response decreases, but not significantly so. However, there is a significant interaction

between ordinal and knower-level here. In addition, there is an interaction between regularity and knower-level. See Figures 2 and 3.

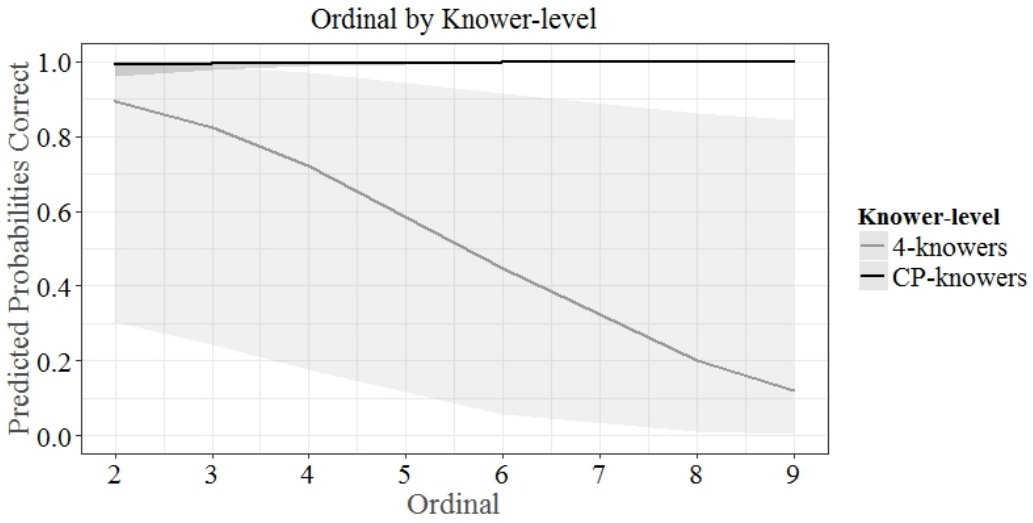

Figure 2: Interaction between ordinal and knower-level.

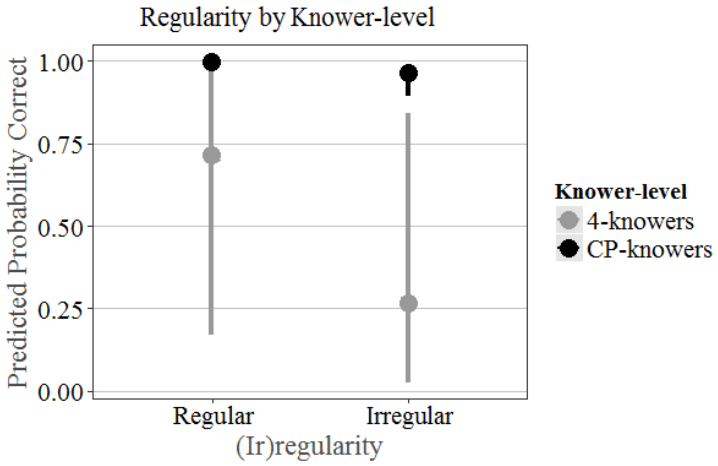

Figure 3: Interaction between regularity and knower-level. Error bars represent 95% confidence interval; note these overlap for regular ordinals.

As Figure 2 shows, CP-knowers' performance is at ceiling across the ordinal count list (with some more variation occurring at the beginning), whereas 4-knowers are less likely to understand higher ordinals than lower ordinals and show greater variation. Figure 3 shows that the effect of knower-level is greater for irregular ordinals than for regular ones.

5.2 Analysis

The outcome of the model aligns with the descriptive data in Table 3 and the ideas put forward above. For one, children's comprehension of ordinals is greater in older children, and greater in CP-knowers than in 4-knowers (note the relatively large estimate in Table 4). The main effect of (ir)regularity shows that regular ordinals are more likely to be understood correctly than *derde* 'third' and *achtste* 'eighth', and the interaction with knower-levels shows that this is especially true for 4-knowers. The lack of an effect of place in the ordinal list suggests children's performance on all (regular) ordinals was more or less stable throughout the list, which is in line with the all-or-nothing type of performance associated with rule-based learning. We go into these points below.

Meyer et al. (in press) found that cardinal acquisition preceded ordinal acquisition, and that cardinal knowledge predicted performance on ordinals: children needed to be at least 4-knowers to provide correct responses on any ordinals, and many children performed better on low ordinals (except *derde* 'third;') than on the higher ordinals *achtste* 'eighth' and *negende* 'ninth'. Our data reflect the same pattern, strongly suggesting that children do need to acquire cardinals before they can acquire ordinals, and that a child's cardinal knower-level better predicts ordinal performance than his or her age. The CP-knowers in our sample were more likely to respond correctly than 4-knowers, and the 2-knowers had to be excluded altogether. This makes sense given that children have to learn that numerals refer to discontinuous quantities (which happens in the 3-knower stage, see Sarnecka, 2015) and ordinals are inherently discrete.

The descriptive data strongly suggested children would perform equally on all ordinals, and this suggestion is reflected in the model as well: there was no significant main effect of place in the ordinal list. This is in line with the idea that ordinals are acquired by means of a rule: before the ordinal formation rule is in place, performance on all (regular) ordinals is

relatively poor, but once the rule is acquired, all forms that follow the rule evoke better performance than those that do not. This is also clear from children's performance on **driede* 'threeth'. This regularized yet ungrammatical form cannot have been encountered in the input, yet children scored as high on **driede* as they did on regular (grammatical) ordinals. Something similar applies to **eende* and **eenste*, regular ordinal versions of *eerste* 'first'. Though *één* 'one' should not be able to serve as a root for ordinal formation (see Barbiers, 2007), children have no difficulty interpreting these forms. These findings support the idea that children are able to decompose ordinal forms and use their morphological structure to arrive at a sensible interpretation, which in turn makes the idea that children rely on purely lexically stored knowledge less likely and rule-based learning more so.

The sensitivity or the exact form of this rule, or more precisely: which suffix(es) children feed into their morphological machinery, cannot be determined on the basis of the comprehension data. If children had massively failed to comprehend *achtste* 'eighth', that would have been clear evidence that their rule only accepts *–de* as an ordinal suffix. However, the data reveal no such major differences in performance between *achtste* 'eighth' and *negende* 'ninth', for example. This could mean that (i) some lexical knowledge is involved, (ii) children recognize *–ste* as an allomorph of *–de*, (iii) children do not find the difference in suffix to be salient or problematic (sloppy "rule"). Performance on this irregular ordinal therefore does not seem affected by its suffix or e.g. its token frequency (though we did not include frequency explicitly in our model, given that the frequency drops as the ordinal list progresses, and the ordinals we tested did not provide us with a means to properly disentangle the two). Despite the lack of a significant main effect of place in the ordinal list, we believe (in line with Meyer et al. in press) that this might play a role, which may become visible in a larger sample. Moreover, note that frequency or place in the count list do not work against *derde* 'third', which evoked many errors, despite being low in the count list and

relatively frequent (*derde* 'third' is at least twice as frequent as *vierde* 'fourth' and four times more frequent than *zesde* 'sixth', let alone *achtste* 'eighth').

Our results differ from Meyer et al.'s in two ways. The first is the presence of an interaction between regularity and knower-level, which is not particularly startling: if ordinals are acquired via a rule, and 4-knowers have yet to fully acquire this rule, then it is not surprising that the exceptions to these rule are even further away from being understood. Second, our model reveals no effect of place in the ordinal list, only as an interaction effect with knower-level. Of course, the children in our sample were somewhat older and more advanced in general, as we lacked children in the lower subset-knower stages and our 4-knowers and CP-knowers performed better overall than the children reported in Meyer et al (in press). Those authors attribute weaker performance on higher ordinal *achtste* to non-linguistic factors; however, since they could not properly disentangle performance on *achtste* (here considered irregular, there regular) from other higher ordinals, it might be that the effect of the suffix was a lurking variable. It might also be that the CP-knowers in our sample are simply past the stage at which these extra-linguistic factors (e.g. not losing count) are clearly visible. Children who perform at or near ceiling provide the model with limited material to work with, leaving it difficult to see whether an effect of ordinal might still be there, or has been there before, and our 4-knowers are so few in number that we could at best speculate about what dictates the variation in their behavior. It also raises the question what factor contributes to the ceiling performance in CP-knowers. Given the data above, we believe cardinal knowledge, or better put: being a cardinal principle knower, is the key component here. The likelihood of providing a correct response as a CP-knower is much greater than as a 4-knower, and it could be that this conceptual leap outweighs the individual effect of ordinal here, whereas for 4-knowers it is precisely this lack of numerical knowledge that outweighs the effect of individual ordinals. We leave this for future work to explore.

In summary, our data support the idea that children understand cardinals before they can fully grasp ordinals, and that they acquire ordinals in a rule-based fashion. We see that *derde* 'third' is more difficult than regular ordinals like *tweede* 'second' and *vierde* 'fourth' and ungrammatical yet regularized forms (**eende, *eenste, *driede*) pose no problems. Note that while this must entail that children see ordinals as complex forms and are able to extract a relevant meaning from an ordinal's parts (at least in the context of this task), the responses to *achtste* 'eighth' do not provide additional evidence for a specific rule that children may be using. For this, we must turn to production.

6. Production

The following data are based on the same children who were discussed above; we excluded the same three subset-knowers that were also excluded from the comprehension analysis. We coded a child's response as correct if both the root and the suffix matched the form used in adult Standard Dutch. Errors were then categorized into one of six different groups, according to the suffix produced (*–de, –ste, –te, –e*), the use of the corresponding cardinal (whether it was preceded by a determiner or not, e.g. *(de) negen* '(the) nine' when the target was *negende* 'ninth'). We combined some of the error categories for the *achtste* 'eighth' items: devoiced realization of *–de* as *–te*, and even reduction to *–e* was considered the same (all as regularized **achtde*), as the distinction was not always clearly audible. All remaining responses (or lack thereof) were coded as 'other'.

6.1 Results

Table 5 provides an overview of the mean proportion of correct responses per elicited ordinal per knower-group.

Ordinal		4-knowers			CP-knowers		
		M	***SD***	***SE***	***M***	***SD***	***SE***
1st	eerste	0.4680	0.41473	0.10708	0.7723	0.03000	0.40249
2nd	tweede	0.4000	0.50709	0.13093	0.8612	0.02377	0.31890
3rd	derde	**0.0000**	0	0	**0.5612**	0.03568	0.47865
4th	vierde	0.4000	0.40297	0.10405	0.8003	0.02374	0.31844
6th	zesde	0.6000	0.50709	0.13093	0.9003	0.01835	0.24615
8th	achtste	**0.0660**	0.13663	0.03528	**0.3277**	0.03002	0.40279
9th	negende	0.5340	0.46823	0.12090	**0.3943**	0.03234	0.43392
last	laatste	0.4667	0.50553	0.22608	0.811	0.04294	0.33258

Table 5: Mean proportions of correct responses on each of the tested items per knower-level.

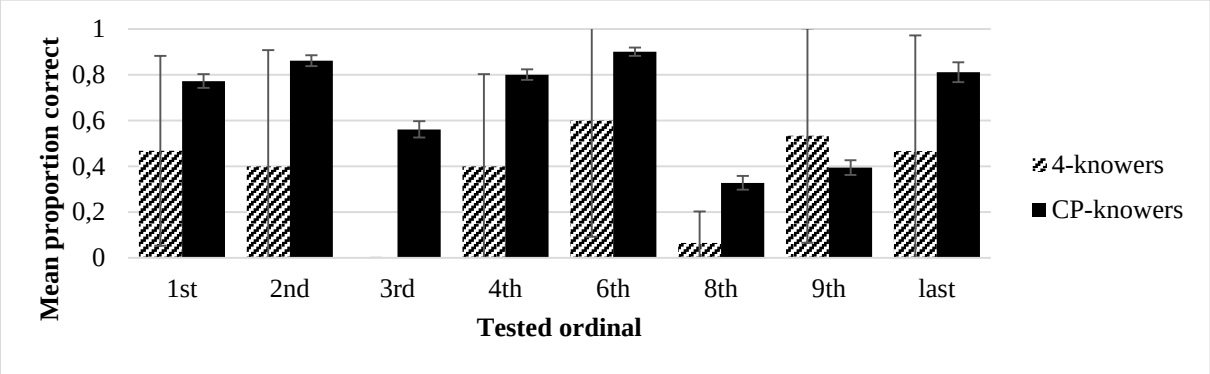

Figure 4: Mean proportions of correct responses. Error bars represent 1 SD.

The table and figure show that 4-knowers only provide a correct response about half of the time for most ordinals. These children score worst on irregular ordinals, with zero correct responses for *derde* 'third' and just one correct response (6.6%) in response to *achtste* 'eighth'. The CP-knowers do better generally, scoring comparably high on regular ordinals *tweede* 'second', *vierde* 'fourth' and *zesde* 'sixth' as on the comprehension test. Here, scores on *tweede* are significantly better than on *vierde* ($Z=-8.604$, $p<0.001$) and *eerste* ($Z=-2.625$, $p<0.009$) but worse than *zesde* ($Z=-4.994$, $p<0.001$). Irregular ordinals elicit fewer correct

responses as well as, interestingly, *negende* 'ninth'. Scores on *achtste* 'eighth' are significantly worse than *derde* (Z=-12.574, p<0.001) and *negende* 'ninth' (-3.690, p<0.001), despite the relatively poor performance on *negende* 'ninth'.

While the above provides some kind of insight in children's performance, we would like a more fine-grained analysis of the factors that may influence adult-like behavior on this task. We therefore fit a generalized linear mixed-effects logistic regression model to determine the effect of different factors on the probability of a correct response, much in the same way as we did for our comprehension test, again leaving out superlatives and testing only the six true ordinals we tested. In addition, we hypothesized that comprehension of a given ordinal might affect production of that ordinal. Because knower-level, age and comprehension scores showed significant (though weak) correlations with one another, we started with a model including just ordinal as a continuous factor and regularity as a binary factor, as well as participant as a random intercept with random slopes for ordinal as a continuous factor. We then tried adding the other three factors in one by one. Adding knower-level as a predictor did not help the model (p=0.6297), adding age as a predictor to the initial model resulted in a significantly improved model (p= 0.0070), but comprehension scores (entered as mean scores per tested ordinal per child) as a predictor to the initial model resulted in an even more significantly improved model p<0.00001), with AIC's dropping from 1097.1 in the initial model to 1072.2 in the model including comprehension scores. Adding knower-level to that model led to a nonsignificant improvement (p=0.1544), but adding age did significantly improve the model (AIC=1067.1, p=0.0077). We therefore only included age as a predictor, not knower-level, leading to the model described in Table 6.

Predictors	**Estimate**	**CI**	**SE β**	***z***	***p***
Intercept	0.787	0.32 – 1.25	0.237	3.321	<0.001
Ordinal	-0.465	-0.61 – -0.32	0.074	-6.320	<0.0001
(Ir)regularity	-1.785	-2.17 – -1.40	0.196	-9.112	<0.0001
Comprehension score	2.139	1.24 – 3.04	0.461	4.642	<0.0001
Age	0.055	0.01 – 0.10	0.020	2.684	<0.0001

Table 6: Result summary for correct responses on 2nd, 3rd, 4th, 6th, 8th and 9th: β coefficient estimates, confidence intervals, standard errors, associated Wald's z-score and significance level (p) for all predictors in the analysis.

From the above, we can see that the fixed factors affect the likelihood of a correct response in the expected directions. For one, the higher the ordinal is in the count list, the less likely it is that a child will provide a correct response. Moreover, irregular ordinals are less likely to elicit a target-like response. Having provided a correct response to a given ordinal in the comprehension task increases the likelihood of a correct response on the production task, as does (to a lesser extent) being older. Though a child's knower-level was a significant predictor for comprehension scores, it does not help explain production scores (beyond what is included within the factor comprehension scores).

We then compared the model in Table 6 to one in which regularity was excluded and ordinal was a categorical (rather than continuous) variable. Though this type of model did not lead to an improvement in the comprehension data, the production model including ordinality as a categorical factor did have a lower AIC than the one including a combination of ordinal as a continuous factor and regularity (1015.0 compared to 1067.1), and this improvement was significant (X^2=58.047, df=3, p<0.0001). Table 7 summarizes this model.

Predictors	**Estimate**	**CI**	**SE β**	***z***	***p***
Intercept	1.161	0.65 – 1.67	0.261	4.447	<0.0001
Ordinal 234-689	-4.563	-6.67 – -2.46	1.074	-4.247	<0.0001
Ordinal 24-3	-2.422	1.63 – 3.21	0.403	-6.008	<0.0001
Ordinal 2-4	-1.402	-2.26 – -0.54	0.438	-3.204	0.0014
Ordinal 69-8	-2.208	-2.71 – 1.71	0.255	-8.806	<0.0001
Ordinal 6-9	-3.412	-4.17 – -2.65	0.388	3.499	<0.0001
Comprehension score	1.840	0.81 – 2.87	0.526	3.499	0.0005
Age	0.062	0.02 – 0.11	0.023	2.675	0.0075

Table 7: Result summary for correct responses on 2nd, 3rd, 4th, 6th, 8th and 9th: β coefficient estimates, confidence intervals, standard errors, associated Wald's z-score and significance level (p) for all predictors in the analysis.

This model shows similar effects for comprehension scores and age: children who performed well on the comprehension task are more likely to do well in the production task, and older children are more likely to succeed than younger ones. However, where this model differs is where it comes to the effect of ordinal. Contrasts in the model above were coded to isolate irregular *derde* 'third' and *achtste* 'eighth' and to mimic going through the count list. The results show that the higher half of the tested ordinals (*zesde*, *achtste* and *negende*, 'sixth', 'eighth' and 'ninth') are less likely to be produced correctly than the lower half. Within the lower ordinals, we can see that irregular *derde* 'third' is less likely to be produced correctly than its regular neighbors, but that the probability of a correct response is lower for *vierde* than *tweede* 'second'. These observations are in line with the idea that morphology affects production, but also consistent with the assumption that higher ordinals are harder. A similar pattern is seen within the high ordinals: *achtste* 'eighth' leads to a lower probability of an adult-like response than its regular neighbors, outweighing the influence of the place in the count list itself, but that *negende* 'ninth' is also harder than *zesde* 'sixth'. The fact that this

model improves upon the former one suggests that the factors regularity and ordinal (continuous) in the previous model explain less of the variance when considered independently than when taken as a combined property within each individual ordinal. This did not hold for our comprehension data, but as we suggested in section 3, children can be more lenient when it comes to interpreting ordinals in context. For production they have to be precise, and other factors specific to each ordinal (e.g. phonological factors) may also play (more of) a role, which would explain why a more precise model considering ordinals individually yields a better result than one that does not.

We might also wonder what children's incorrect responses look like. After all, rule-based learning typically goes hand in hand with one particular kind of error: overgeneralizations. Though most children provide too few errors to say anything about the consistency within those errors, Figure 5 below shows the distribution of answers for each of the tested ordinals for each of the knower-level groups together. Percentages reflect the percentage of a given response type overall.

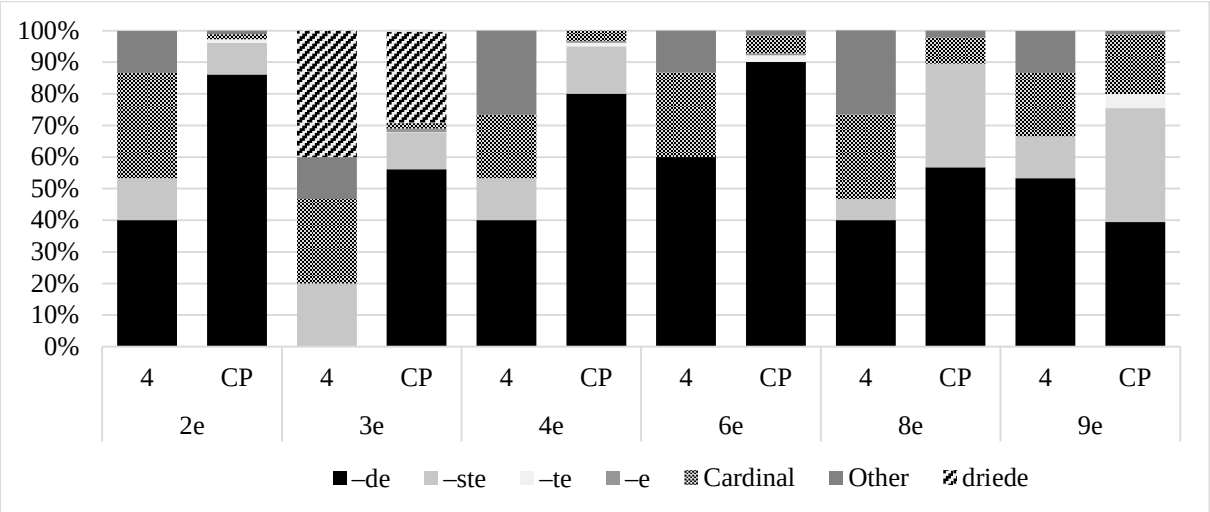

Figure 5: Distribution of responses per target ordinal per knower-level.

Figure 5 shows that while the distribution of response types differs somewhat between each ordinal for each knower group, some general tendencies are also clear. For example, when a

4-knower provides an incorrect response, chances are the child will produce the corresponding cardinal numeral in the place of the ordinal, whereas CP-knowers who make errors tend to overuse the suffix *–ste*, i.e. say **negenste* rather than *negende* 'ninth'.[10] *Negende* is also the ordinal where this answer type occurs most often, and the only regular ordinal where production and comprehension scores do not align (of the responses from children with perfect comprehension scores on *negende*, 58.05% were incorrect; this percentage is under 20% for the other three regular ordinals). Note that the *–ste* bars on *achtste* 'eighth' represent correct responses, not errors, which also makes it immediately obvious that *–de* is the preferred form there. Most children provided consistent responses to the *achtste* 'eighth' trials: 55.39% never produced the correct form, while 18.46% always did.

Perhaps the most striking response pattern is found for *derde* 'third'. None of the 4-knowers produced *derde* on the appropriate trials; CP-knowers did so roughly half the time. The vast majority of errors were overgeneralizations of the cardinal root: **driede* (striped bars), or **drieste*, rather than *derde* (solid black bar). Overgenerations of *–ste* with the appropriate root allomorph (i.e. **derste*) were not attested. Note that we expected that children who could not comprehend *derde* 'third' would also not produce it correctly. Only three of the correctly produced utterances on *derde* came from children who failed to find the third on all of the comprehension items, as opposed to 57 incorrect responses within the same group, and the child with one correct response on the comprehension task did not produce *derde* correctly once. Moreover, children who are able to find the third card on (nearly) all

[10] Many of these cardinal forms were, strictly speaking, not adult-like analytic ordinals: sometimes a determiner was used for example (**de drie*), and cases like *auto (nummer) drie* 'car (number) three' hardly ever occurred. These might be considered a type of conversion; conversion has been thought to be easier than derivation in acquisition (Clark, 2014). More important, however, is the observation that responses such as *(de) auto (nummer) drie* '(the) car (number) three' are relatively rare. Colomé & Noël (2012) hypothesized that French-speaking children might prefer such analytic ordinals, but neither they nor we find clear support for this idea.

the comprehension trials, sometimes still struggle with production: within the group of children who had perfect comprehension scores, 27% of the production trials were incorrect.

The response patterns above differ considerably for *eerste* 'first', as Table 8 shows. As with comprehension, children typically provided correct responses.

	4-knowers		CP-knowers	
	Number	Percentage	Number	Percentage
Correct	7	47%	139	77%
*Eende	0	0%	7	4%
*Eenste	1	7%	14	8%
Een(e)	2	13%	5	3%
Voorste	4	27%	13	7%
Other	1	7%	2	1%
Total	15	100%	180	100%

Table 8: Distribution of elicited responses to *eerste* 'first' per knower-level.

Table 8 shows non-targetlike responses were mostly of a different nature than the errors seen for *derde* 'third'. Only rarely did we see e.g.**eende* or **eenste*, or use of *één* 'one' instead of *eerste*; most often children produced a perfectly grammatical alternative superlative form: *voorste* 'lit: frontmost'.

When taken together, we see overuse of both suffix types (i.e. *–de* in the case of *achtste* 'eighth' and occurrences of *–ste* elsewhere, especially on *negen* 'nine': **negenste*). Sometimes the suffix is absent altogether and just the cardinal (or a cardinal with a determiner) is produced. These patterns also occur in response to *derde* 'third' stimuli, where we see children adding one of those suffixes to *drie* to arrive at an ordinal for three (**driede, *drieste*), rather than using the irregular yet grammatical form *derde* 'third'. (The form

**derste* does not occur.) However, using *een* as a cardinal base to produce a regularized ordinal for *first* is much less common, as children tend towards an alternative in the superlative domain here.

6.2 Analysis

The results on the Tell Me production task align neatly with the idea that morphological structure plays an important role in producing ordinals correctly. Put in general terms, our reasoning was that children take in forms from the input, discover that they can decompose them to disentangle their meaning, after which they are able to use an ordinal formation rule to produce regular ordinals in the appropriate contexts as well. Irregular ordinals, which do not transparently follow the rule, have to be learned separately and thus follow later (i.e. after acquisition of the rule).

Following this reasoning, one would expect that regular ordinal production comes in around the same time as the child discovers the rule, or slightly thereafter. For irregular forms, we expect production to follow comprehension of the rule (not necessarily of the corresponding item in comprehension). Children who actively use a rule to produce ordinals, are likely to overgeneralize this rule to the irregular instances (*derde* 'third' and *achtste* 'eighth'). This is what we found: not only did production generally lag behind comprehension, this was especially true for the two irregular forms *derde* 'third' and *achtste* 'eighth'. The problem appeared to be more persistent in the latter case, as more errors occurred on *achtste*–trials than on those targeting *derde*. Since our statistical analysis does not allow for us to test for the effects of the type of irregularity, we cannot say whether this suggests that root allomorphy is easier to overcome than the alternative suffix on *achtste* (for saliency or frequency reasons), or whether the place in the ordinal count list (see also Table 7) is the deciding factor. Counting up to the higher ordinal is conceivably more taxing, which

may mean the added burden of the exception is too much for some children. In any case, nothing in the above provides evidence against the rule-based approach to ordinals, and the observation that it is these irregular ordinals that trail behind regular forms in fact supports it.

The nature of the errors also provides further support for a rule-based learning approach. Most importantly, the regularized yet ungrammatical form **driede* is preferred over its grammatical counterpart in which root allomorphy is present. The widespread occurrence of this form shows that children are actively using some sort of rule during the production task, as this form is ungrammatical and therefore not in the input. We also find overgeneralizations of *–de* on *achtste* (**achtde*) and to a lesser extent *–ste* on other ordinals (**tweeste*). This means that children consider these suffixes as alternatives for one another: they both make ordinals when added to a cardinal. The question is why some children would prefer one form over the other. The *–de* overuse is the most frequent but perhaps not so exciting: if the input provides mostly evidence from ordinals under *twintigste* 'twentieth', then children have much more evidence for *–de* than for *–ste*, and so the overgeneralization is clearly input-driven. How then to account for those few children who prefer *–ste*? Surely this must mean children are also considering evidence from higher ordinals (over *twintigste* 'twentieth') for the ordinal rule, to the extent that *–ste* receives default or elsewhere status and *–de* is considered an exception or more specific instance. (See e.g. Yang 2017 for an account of how input, and how much input, is needed to account for rules and the exceptions to these rules.)

Interestingly, items that set out to elicit *eerste* 'first' evoked different patterns. Forms like **eende* and **eenste* are nearly non-existent in production, for example. The frequent use of **driede* already shows that ungrammaticality in adult Dutch (and hence absence from the input) cannot be the cause for the lack of these regularized *first*-forms in our data, but we are also unable to draw a definitive conclusion on the basis of this task. One possible explanation

could be that *eerste* 'first' is so frequent that it holds a clear and established position in the child's lexicon, and that this form blocks or prevents overregularizations of the **eende* type (similar to the way *went* blocks **goed* or *best* blocks **goodest*; cf. Embick & Marantz 2008 for theoretical and comparative discussion of blocking in DM and other approaches). However, if some sort of blocking were a likely explanation, then we would also expect other alternatives to *eerste* to be blocked, yet many children who can find the *eerste* in the comprehension task produce *voorste* 'frontmost' in the production task. Note, moreover, that *voorste* and *eerste* are both perfectly grammatical superlatives, making *voorste* also a closer alternative to *eerste* than the ordinals **eende* and **eenste*. This suggests that children may already have fairly precise knowledge of other ordinal properties. As Barbiers (2007) argues, *een* 'one' lacks the feature composition required for ordinal formation; if children have this feature specification in place, that would mean **eende* is not coincidentally absent, but inherently impossible. These regularized forms are therefore not suitable alternatives to *eerste* 'first' in the context of the task, but the superlative *voorste* 'frontmost' is a syntactically and semantically viable option. Further research would be needed to investigate children's knowledge of ordinal features, and what leads some children to prefer *voorste* over *eerste*.

Section 3 also commented on the role of cardinal knowledge, age, place in the count list and comprehension scores. Our mixed-effects model revealed expected main effects of age, place in the ordinal count list, and comprehension scores, but knower-level was not found to significantly improve the model. This suggests that once the comprehension is taken into consideration, cardinal knowledge does not add anything extra to that.

One question pertains to **negenste*: if most children produce **achtde* 'eighth' and hardly any children systematically overgeneralize *–ste* to all ordinals, then why is **negenste* such a frequent error? Individual response patterns suggest there might be a neighboring effect: of the 21 children who produced *negenste* at least twice (out of three trials), only three

always produced **achtde;* 11 always produced *achtste* correctly and the others produced a mix. Put differently: once the child switches suffix, he or she might switch to that suffix for the next ordinals. This is also consistent with one of the patterns attested in dialects of Dutch (Sleeman 2017). Of course, further investigation is needed to see if children maintain *–ste* through higher ordinals consistently.

Our production data together support the idea that ordinals are acquired in a rule-based fashion. We see that comprehension precedes production, and that regular ordinals are nearly all produced properly at around the same time, and that overgeneralization errors all point in the direction of the application of a rule. For most children, that rule means attaching a suffix *–de* to a cardinal base. In a small group, *–ste* is overgenerated across the board.

7. Conclusion

The goal of this study is to investigate whether Dutch children acquire ordinals in a rule-based fashion, and whether there are other factors (numeric-conceptual difficulties, frequency, extra-linguistic factors) that play a role in this process. Unlike previous work, which focusses on comprehension only, our perspective is comparative: we discuss data from a comprehension task and a production task we administered to 68 typically-developing monolingual Dutch children between the ages of 3;3 and 6;0. The results are in line with the findings and the proposed acquisition path presented in Meyer et al. (in press): cardinal knowledge and ordinal rules rule, age, token frequency and other factors are less important than morphological transparency.

The comprehension test supported the earlier (intuitive) finding that substantial cardinal knowledge is in place before ordinals are acquired: the two-knowers in our study were not able to identify ordinals correctly at all, four-knowers performed worse than CP-knowers and performance on ordinals was generally worse than on cardinals. The first step towards

understanding ordinals seems to begin with the superlative *eerste* 'first', quickly followed by the regular ordinals e.g. *tweede* 'second, lit: twoth' and *vierde* 'fourth'. The effect of the place in the ordinal count list seems to matter less than in the Meyer et al. (in press) study, as no main effect of ordinal was found here and only 4-knowers did worse on higher ordinals than lower ones. (This is unsurprising, given that 4-knowers by definition only understand low cardinals as well.) Moreover, performance was worst on the irregular ordinal *derde* 'third', suggesting that the form of the ordinal influences acquisition. The effect of irregularity was visible on *achtste* 'eighth', but to a much lesser extent.

That the form is important is further supported by the comprehension data we collected for the regularized yet ungrammatical form **driede* 'three–th', and even **eende* 'one–th' and **eenste* 'one–st'. These forms are absent from the input, yet children have no difficulty discerning what they must mean. In fact, performance on **driede* was even better than on its grammatical counterpart. This suggests they are decomposing these forms on the spot, actively applying a rule to reach an appropriate interpretation.

The production data also support productive use of an ordinal formation rule: where adults would produce *derde* and *achtste,* children often respond with **driede* and **achtde*, overgeneralizing the rule in both cases. In **driede* the root allomorphy is not realized, and in **achtde* the suffix for low ordinals is used. Interestingly, the fact that **eende* and **eenste* almost never occur suggests that these forms are not competitors for *eerste*, though we leave the reasons for this open for further study. The preference in some children for the form **negenste* instead of *negende* 'ninth' is also an observation worthy of further exploration.

Another obvious route for future research is to investigate whether children acquiring languages with more irregular count lists (such as English) also employ a rule to acquire ordinals, or whether lexical learning makes more sense for these children. Would, despite the many exceptions at the very beginning of the ordinal list, a rule-based approach

(computation) still be more economical than acquiring ordinals in the same one-by-one fashion cardinals are acquired (storage)? Of course, this would have implications for how children treat the input before having acquired such ordinals. For now, however, we conclude that at least Dutch-speaking children acquire ordinals in a rule-based fashion, and leave learners of other languages for future study.

Acknowledgements

Intentionally left blank while under review.

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