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Reference

BARROUILLET, Pierre Noël, THEVENOT, Catherine, FAYOL, Michel. Evidence for knowledge of the syntax of large numbers in preschoolers. *Journal of Experimental Child Psychology*, 2010, vol. 105, no. 3, p. 264-271

DOI : 10.1016/j.jecp.2009.10.005

Journal of Experimental Child Psychology 105 (2010) 264–271

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Brief Report

Evidence for knowledge of the syntax of large numbers in preschoolers

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ARTICLE INFO

Article history:
Received 23 June 2009
Revised 22 October 2009
Available online 27 November 2009

Keywords:
Numerical cognition
Incidental learning
Cognitive development
Implicit learning
Short-term memory
Verbal code

ABSTRACT

The aim of this study was to provide evidence for knowledge of the syntax governing the verbal form of large numbers in preschoolers long before they are able to count up to these numbers. We reasoned that if such knowledge exists, it should facilitate the maintenance in short-term memory of lists of lexical primitives that constitute a number (e.g., *three hundred forty five*) compared with lists containing the same primitives but in a scrambled order (e.g., *five three forty hundred*). The two types of lists were given to 5-year-olds in an immediate serial recall task. As we predicted, the lists in syntactic order were easier to recall, suggesting that they match some knowledge of the way lexical primitives must be ordered to express large numerosities.

Introduction

The acquisition of the number list has been described as a slow and laborious process, especially for children speaking languages such as English that, contrary to Chinese, do not map directly onto the Hindu-Arabic number system (Miller, Kelly, & Zhou, 2005). Although the rules used to generate large numbers (e.g., *two hundred forty five*) are more consistent and transparent than those governing the construction of the initial part of the list that must be learned by rote (i.e., from *one* to *twenty*), children need to acquire a complex set of syntactic rules combining a limited number of lexical primitives, rules leading to surprising peculiarities in some cases. For example, young French speakers need to understand that although *cent neuf* (*one hundred and nine*) and *neuf cents* (*nine hundred*) are two legal chains, *cent dix* (*one hundred and ten*) is legal but *dix*

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0022-0965/$ - see front matter
doi:10.1016/j.jecp.2009.10.005

cent (literally *ten hundred*) is not, whereas *onze cents* and *douze cents* (*eleven hundred* and *twelve hundred,* respectively) are perfectly legal as well as *cent onze* and *cent douze* (*one hundred and eleven* and *one hundred and twelve,* respectively). However, the learning of the syntax of large numbers is relatively fast compared with the acquisition of the beginning of the number list, which is surprisingly slow and difficult. Whereas English speakers can recite the list up to 10 long before the end of their third year of life, 5-year-olds can reach only 40 on average, with children experiencing particular difficulties at each decade boundary (Miller et al., 2005). This slow acquisition of the list up to 100 is even more difficult in French (of France), where complex decades *soixante dix* (literally *sixty ten*) and *quatre vingt dix* (literally *four twenty ten*) are used to express *seventy* and *ninety,* respectively (Jarlegan, Fayol, & Barrouillet, 1996). By contrast, second graders know the list up to 1,000 and often far upward. Of course, systematic tuition in elementary school and learning to write numbers in their Hindu-Arabic format play a crucial role, but it is also probable that this rapid learning is facilitated by prior knowledge about how lexical primitives can be combined to form large numbers. The aim of the current study was to provide evidence of this knowledge in young children long before they learn to name and write large numbers.

As stressed by Perruchet and Pacton (2006), most of our abilities reflect some kind of adaptation to the regularities of our environment. This learning process that occurs without intention to learn and without a clear awareness of what we are learning and what we know was called *implicit learning* by Reber (1967). Interestingly, most of the studies on implicit learning have investigated individuals' capacity to learn the rules of artificial grammars governing the order of letters within short strings. Typically, after a study phase of approximately 10 min during which participants are presented with letter strings produced by the grammar, they are asked to judge the grammaticality of new strings. Surprisingly, whereas people do not report explicit knowledge of the grammar rules, they are able to categorize these new strings far above chance level, suggesting that they have acquired an implicit knowledge about the way regular strings can be formed. Several theoretical accounts of this learning process have been put forward. The first account suggested that people abstract the structural nature of the stimulus environment and the grammar rules during learning and use this knowledge to categorize items during the test phase (Reber, 1967). This abstractionist account was challenged by associationist interpretations suggesting that people do not abstract rules whose knowledge would remain implicit; rather, they memorize the strings under study and then base their judgments of grammaticality on the similarity between the new strings and these memory traces (Vokey & Brooks, 1992). Perruchet and Pacteau (1990) went further by suggesting that the explicit knowledge of fragments of these strings would be sufficient for explaining this grammatical learning. Thus, contrary to the abstractionist view, these associationist explanations suggest that there is no implicit knowledge of the rules that have not been acquired; rather, there is explicit knowledge of some recurrent co-occurrences that are sufficient to evaluate grammaticality.

Whatever the theoretical account that one favors, two aspects of this phenomenon of learning through the repeated exposure to regularities are of particular relevance for the acquisition of number knowledge by preschoolers. First, it has been demonstrated that this kind of learning is based on processes that remain unaffected by developmental differences and, thus, is perfectly efficient in preschoolers (Meulemans, Van der Linden, & Perruchet, 1998; Vinter & Perruchet, 2000; but see Maybery, Taylor, & O'Brien-Malone, 1995). Second, the studies evoked above indicate that people can become sensitive to subtle environmental regularities such as frequent co-occurrences and perhaps syntactic rules. Thus, in the same way as experiment participants acquire an intuition of what sequence is legal and what sequence is illegal after only minutes of exposure to artificial material, it is possible that young children acquire some knowledge about the finite state grammar governing the syntax of large numbers. Indeed, universal constraints govern the construction of numeral systems through phrase structure rules denoting additive and multiplicative relations (Hurford, 2007). For example, when combining units (U) and decades (D) with the word *hundred* (H), only two of the six possible sequences are legal (i.e., UHD and HDU) and there is only one way to combine a particular (P) and a decade with *hundred* (i.e., PHD), whereas two primitives belonging to the same category (i.e., U, D, or P) never can be produced in immediate succession.

However, despite the similarities between finite state artificial grammars used in implicit learning studies and the syntax of numbers, the paradigm of grammaticality judgment cannot be used directly.

Seron and Fayol (1994) used such a task in which children were asked to indicate whether a sequence of primitives was correct or not, but their participants were second graders (mean age of 7 years 4 months) and it would probably not make sense for preschoolers to judge whether the string *three forty hundred nine* is a number or not. Thus, a more indirect method was needed where knowledge about the structure of numbers influences participants' behavior in a task that does not explicitly target this knowledge. In the current study, we took advantage of the well-known influence of long-term memory on short-term memory. It has often been demonstrated that short-term memory performance is enhanced when the material under study matches long-term knowledge. For example, in immediate serial recall task, words are easier to recall than nonwords (Hulme, Maughan, & Brown, 1991) and words forming a meaningful sentence are easier to recall than the same words presented at random (Baddeley, Vallar, & Wilson, 1987). The effects of long-term memory on short-term memory have also been observed in children (Gathercole, 1998). For example, it has been shown that immediate recall of nonwords by 7- and 8-year-olds is facilitated when these nonwords contain phoneme pairs that are high in probability of occurrence in children's language (Gathercole, Frankish, Pickering, & Peaker, 1999). Majerus and Van der Linden (2003) reported that these effects of long-term memory on short-term memory are equivalent in both 6-year-olds and adults.

In the same way as young children acquire knowledge about the phonotactic structure of their language, it is possible that the repeated exposure to large numbers leads them to acquire knowledge about recurrent successions of lexical primitives in numerals. Suppose that young children are presented with either legal or completely illegal strings in which each transition violates a syntactic rule (e.g., *three hundred forty nine* vs. *three nine forty hundred*). There is some probability that legal strings contain chunks already encountered and stored in long-term memory, something that is impossible with illegal strings that must be encoded as a series of independent primitives. Thus, if the hypothesis of children's incidental learning of the syntax of large numbers is correct, and following Gathercole and colleagues' (1999) and Majerus and Van der Linden's (2003) studies, young children should achieve a better immediate serial recall of legal strings of lexical primitives than of illegal ones. The following experiment tested this prediction in 5-year-old preschoolers. The illegal sequences were created by scrambling the constitutive primitives of large numbers in such a way that they did not contain any syntactically allowed transition (see our example above). To achieve a more accurate comparison between these two conditions, children studied series that were tailored to their own digit span.

Method

Participants

A total of 49 children between 4 years 9 months and 6 years 1 month of age (M = 5 years 6 months, SD = 3.9 months, 23 girls and 26 boys) from a middle-class suburban area volunteered to participate with parental consent.

Material and procedure

The material consisted of 10 lists of 2 to 6 lexical primitives chosen in such a way that these primitives could be arranged either in an order leading to a syntactic chain corresponding to a number in French (of France) or in an order where each transition between adjacent terms was illegal (e.g., *trois six vingt cent* and *six cent vingt trois,* corresponding to *three six twenty hundred* and *six hundred and twenty three,* respectively), resulting in legal and illegal lists (see Appendix). This constraint was respected for all of the lists except the 6-word lists because the production of 10 totally illegal lists of this length obliged us to construct lists with the same structure that could induce a bias in the memory experiment. Each lexical primitive was registered by a neutral female voice using Cool Edit Pro software. We constituted the lists by concatenating the corresponding records in immediate succession (i.e., without pause between them) so as to produce a continuous speech stream without any prosodic feature.

Prior to the experimental task, children performed a counting task and a digit span task to evaluate their explicit knowledge of the number list and their short-term memory span for numerical material.

In the counting task, children were asked to recite the number list as far as they could. The digit span task was a subtest of the Wechsler Intelligence Scale for Children (WISC-IV) in forward order. Children were presented with lists of 2 to 8 digits in the ascendant order with two lists of each length. The experimenter read the digits aloud at a rate of one digit per second for immediate serial recall. The task ended with the failure to recall both lists of a same length. The span was given by the longest list recalled in correct order. Then the experimenter introduced the critical task as another immediate serial recall task but controlled by the computer. Children were presented with lists whose length depended on their own digit span, with 10 lists at each of the span – 1, span, and span + 1 lengths. Half of these lists were presented in legal order, and the others were presented in illegal order. The lists presented in their legal and illegal forms were counterbalanced across participants. Four different fixed random orders of presentation of these lists were created, with children being randomly assigned to one of these orders. Children were asked to listen carefully to the voice on the computer and to recall all of the words in correct order when a well-known cartoon character appeared on screen. The score was the number of lists recalled in correct order.

Results

In the counting task, the lengths of the number lists produced by children ranged from 6 to 79 with a mean of 33.8 ($SD = 16.4$). Thus, none of the studied children knew the number list up to 100. Their mean digit span was of 3.69 ($SD = 0.74$), with 23 children exhibiting a span of 3, 18 children exhibiting a span of 4, and 8 children exhibiting a span of 5. Interestingly, the higher the span, the longer the number list produced, $r = .40$, $p < .01$, with children with spans of 3, 4, and 5 reaching averages of 27, 36, and 45, respectively, when counting. Counting performance was also related to age, with older children knowing a longer portion of the number list, $r = .39$, $p < .01$, but the correlation between span and counting remained significant even when the effect of age was partialled out, $r = .37$, $p = .01$.

So far as the memory task was concerned, a 3 (List Length: span $-$ 1, span, or span + 1) $\times$ 2 (Type of List: legal or illegal) analysis of variance (ANOVA) with the two factors as within-participant variables was performed on the number of lists correctly recalled. There was a trivial effect of list length, with the percentage of lists correctly recalled decreasing as this length increased (88%, 59%, and 16% for span $-$ 1, span, and span + 1 lists, respectively), $F(2, 96) = 295.02$, $p < .001$, $\eta_p^2 = .86$. More interestingly, and as we predicted, there was a small but reliable effect of the type of lists, with legal lists being better recalled than illegal lists (57 and 51%, respectively), $F(1, 48) = 6.17$, $p < .02$, $\eta_p^2 = .11$, an effect that did not interact with list length, $F < 1$ (Fig. 1). These results were replicated when the analyses were run with the material as a random variable in a 5 (List Length: 2, 3, 4, 5, or 6 words) $\times$ 2 (Type of List: legal or illegal) ANOVA with the second factor as a repeated measure. Beyond the trivial effect of list length, $F(4, 45) = 104.84$, $p < .001$, $\eta_p^2 = .90$, lists were better recalled in their legal order than in their illegal order, $F(1, 45) = 6.99$, $p < .02$, $\eta_p^2 = .13$, an effect that did not significantly interact with list length, $F(4, 45) = 1.72$, $p > .10$, $\eta_p^2 = .13$. The better recall of legal lists was independent from the age of participants, $r = -.16$, $p > .20$, and from their performance on the counting task, $r = .11$, $p > .20$. In the same way, it did not vary significantly with the digit span of the children, $r = -.11$.

It is worth noting that the effect was not restricted to a subgroup of children. Among the 49 children, 29 exhibited a better recall of legal lists than of illegal lists, whereas only 13 exhibited a reverse effect (Fig. 2). Nonetheless, although the effect was significant in children with a span of 3 (66% and 60% of legal and illegal lists correctly recalled, respectively), $t(22) = 1.72$, $\eta_p^2 = .12$, $p < .05$ (one-tailed), and a span of 4 (53% and 45%, respectively), $t(17) = 2.07$, $\eta_p^2 = .20$, $p < .05$ (one-tailed), it did not appear in children with a span of 5, with the percentage of lists correctly recalled not being higher for legal lists than for illegal lists (37% and 38%, respectively). The lower rate of correct recall in children with a span of 5 could account for this phenomenon; most of the lists presented were too long for them, with only 30% of correct recall for the list at span (5 words) and 8% for the span + 1 lists (6 words). This was probably due to the fact that the lists of lexical primitives often contained longer words (e.g., bisyllabic words such as *quarante* [*forty*]) that are more difficult to maintain than the monosyllabic words involved in the digit span used to assess children's spans.

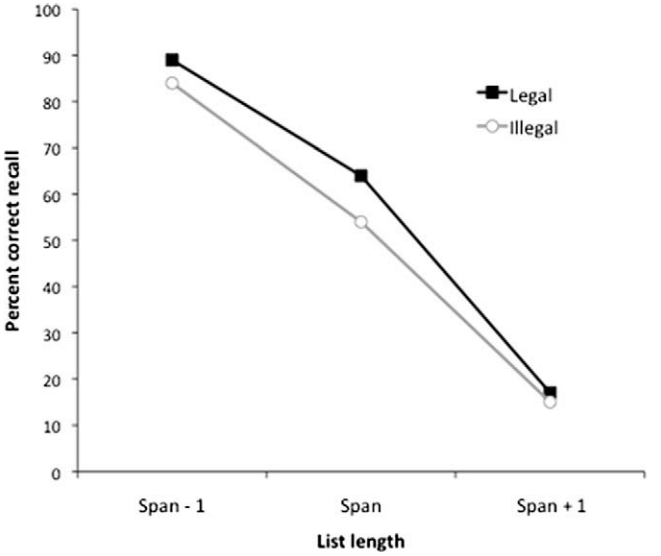

Fig. 1. Percentages of lists correctly recalled as a function of their length and their compliance to the syntactic rules.

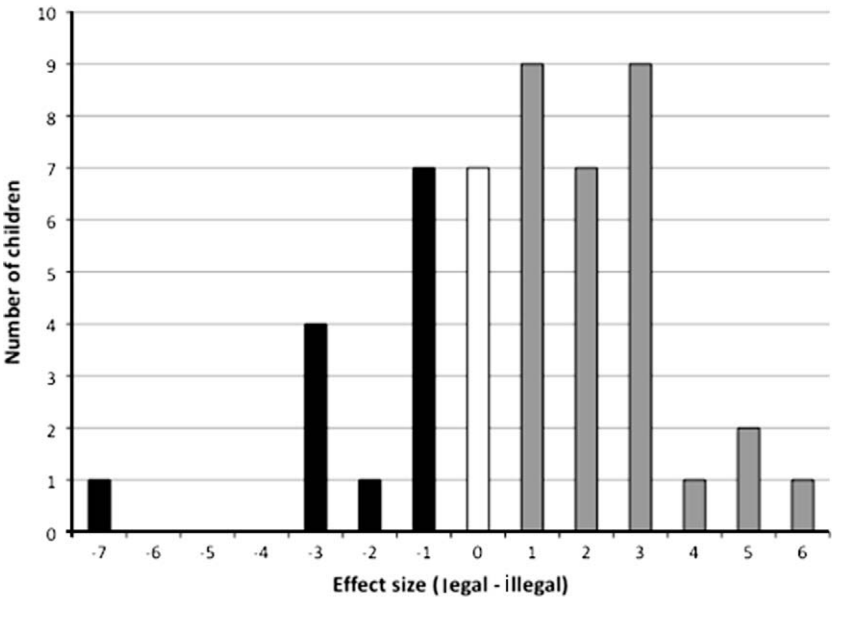

Fig. 2. Distribution of the size of the effect of legality among children.

Discussion

The aim of this study was to investigate the existence of knowledge about the syntax of large numbers in young children long before they are able to count up to these numbers and use them. As we observed, 5-year-olds know only the very beginning of the number list, knowledge that seems at least partly related to short-term memory capacities as the significant correlation between counting performance and digit span testified, a relation consistent with prior work showing that counting requires working memory resources (Healy & Nairne, 1985). To the best of our knowledge, this relation that echoes the well-known role of the capacity of the phonological loop on vocabulary acquisition (Gathercole & Baddeley, 1989) has never been reported before. Note that, exactly in the same way as the causal directionality of the relationship between verbal short-term memory and receptive vocabulary development has been questioned (Brown & Hulme, 1996), the directionality of the relationship observed here is open to question. On the one hand, it could be assumed that higher capacities in short-term memory would facilitate the learning of the number list, as Gathercole and Baddeley (1989) assumed that verbal short-term memory facilitates the acquisition of new words; on the other hand, it could also be assumed that better knowledge and higher familiarity with the number list would facilitate encoding and retrieval of number words in the digit span task. Further studies are needed to track the developmental path of this relationship and decipher the problem of its directionality. Nonetheless, despite preschoolers' limited knowledge of the number list, the current study indicates that preschoolers are better able to recall lists of lexical primitives in a legal syntactic order corresponding to a large numerosity than in a scrambled order violating the syntactic rules.

Our account of this phenomenon is that through the repeated exposure to the verbal form of large numbers produced by siblings, parents, and media, children acquire some knowledge of the way large numbers are constructed. However, the nature either implicit or explicit of this knowledge remains an open question. Indeed, our results do not necessarily imply that preschoolers have abstracted from this input the syntactic rules governing the construction of large numbers. As suggested by Perruchet and Pacteau (1990) in their account of the implicit learning of artificial grammars in adults, it is possible that preschoolers have memorized recurrent fragments of large numbers through the form of chunks that in turn govern the parsing of the verbal input and direct its encoding. This encoding would facilitate the maintenance and retrieval of the lexical primitives to recall. As we noted above, Perruchet and Pacteau (1990) conceived the fragmentary knowledge they described as conscious and not implicit. Thus, the better recall of the legal lists we observed here could result from children's explicit knowledge of some 2- or 3-word fragments frequently encountered. This does not necessarily mean that the effect we observed was due exclusively to the explicit knowledge of DU numbers that children are able to recite. Indeed, if this were the case, the effect resulting from the presentation of syntactic lists should vary as a direct function of the length of the number list that children can recite. Actually, the correlation between the performance in the counting task and the size of the experimental effect in 4-word lists studied by all children was practically nil with $r = .01$. Moreover, the nature of the numbers eliciting the strongest effects is at odds with this simplistic account. For example, among these numbers were *neuf cent un* (*nine hundred and one*), *mille deux cent cinquante* (*one thousand two hundred fifty*), and *six mille deux cent trente* (*six thousand two hundred thirty*), which do not contain DU forms.

A more plausible account of the result reported here is probably to assume that children have stored in long-term memory through incidental learning knowledge (perhaps explicit) about recurring chunks that goes beyond what they are able to exhibit when reciting the number list. This knowledge has facilitated the encoding and retrieval of the lists when presented in syntactic order, knowledge that could not be matched by the scrambled lists. Thus, the implicit learning already observed in children's acquisition of French orthographic regularities about the frequency of double consonants, their legal position within the words, the impossibility to double a vowel, and morphological constraints (Pacton, Fayol, & Perruchet, 2005; Pacton, Perruchet, Fayol, & Cleeremans, 2001) seems to extend to the syntactic structure of numbers. This learning probably plays a role in the fast acquisition of the number list once the difficulties inherent in the first steps of this acquisition have been overcame as well as in the acquisition of rules for transcoding large numbers from their verbal form to their Arabic form before the meaning of these numbers has been clearly understood (Barrouillet, Camos, Perruchet, & Seron, 2004). In each case, the massive exposure to material presenting strong statistical regularities seems sufficient for the acquisition of knowledge even in young children before any systematic tuition.

Acknowledgment

The authors thank Emma Klein for collecting and sorting the data.

Appendix

2-Word lists		
Cent Trente	130	Trente cent
Cent un	101	Un cent
Cent dix	110	Dix cent
Vingt Cinq	25	Cinq vingt
Cent Vingt	120	Vingt cent
Soixante seize	76	Seize soixante
Quarante trois	43	Trois quarante
Soixante Dix	70	Dix soixante
Trente quatre	34	Quatre trente
Cent cinquante	150	Cinquante cent
3-Word lists		
Deux cent quarante	240	Deux quarante cent
Neuf cent un	901	Neuf un cent
Quatre vingt douze	92	Vingt douze quatre
Cent dix neuf	119	Neuf dix cent
Cinq cent trente	530	Cinq trente cent
Cent trente six	136	Six trente cent
Cent cinquante sept	157	Sept cinquante cent
Cent soixante dix	170	Dix soixante cent
Soixante dix sept	77	Sept dix soixante
Quatre vingt dix	90	Quatre dix vingt
4-Word lists		
Quatre vingt dix neuf	99	Neuf quatre dix vingt
Trois cent vingt six	326	Trois six vingt cent
Quatre vingt dix sept	97	Sept vingt dix quatre
Deux cent quarante trois	243	Trois deux quarante cent
Seize cent quatre vingt	1,680	Quatre seize vingt cent
Mille deux cent cinquante	1,250	Deux cinquante cent mille
Trois mille dix huit	3,018	Huit dix trois mille
Cinq cent soixante douze	572	Cinq douze soixante cent
Dix huit cent treize	1,813	Treize huit dix cent
Cent quatre vingt six	186	Quatre six vingt cent
5-Word lists		
Cent quatre vingt dix sept	197	Quatre sept vingt dix cent
Mille cent soixante dix sept	1,177	Sept dix soixante cent mille
Huit cent quatre vingt neuf	889	Neuf quatre huit vingt cent
Cent quatre vingt dix huit	198	Quatre huit vingt dix cent
Deux mille cinq cent un	2,501	Deux cinq un cent mille
Six mille deux cent trente	6,230	Deux six trente cent mille
Quatorze mille quatre vingt deux	14,082	Quatre quatorze deux vingt mille
Dix huit cent quarante trois	1,843	Huit dix trois quarante cent
Sept cent quatre vingt cinq	785	Quatre sept cinq vingt cent
Dix neuf cent soixante douze	1,972	Neuf dix douze soixante cent
6-Word lists		
Dix huit mille cent vingt deux	18,122	Deux huit dix vingt cent mille
Quatorze mille six cent vingt huit	14,628	Mille six huit quatorze vingt cent
Cent cinquante trois mille soixante dix	153,070	Mille trois cinquante dix soixante cent
Cent soixante sept mille trente quatre	167,034	Quatre sept trente soixante cent mille
Neuf mille deux cent soixante douze	9,272	Mille deux douze neuf soixante cent
Treize mille cinq cent quarante huit	13,548	Huit cinq treize quarante cent mille
Deux mille six cent trente cinq	2,635	Six deux cinq trente cent mille
Dix neuf cent quatre vingt trois	1,983	Trois neuf quatre dix vingt cent
Cent un mille quatre vingt quatorze	101,094	Un quatre quatorze vingt cent mille
Dix sept cent soixante dix neuf	1,779	Sept neuf dix dix soixante cent

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