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Numerosity and number signs in deaf Nicaraguan adults

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Abstract

What abilities are entailed in being numerate? Certainly, one is the ability to hold the exact quantity of a set in mind, even as it changes, and even after its members can no longer be perceived. Is counting language necessary to track and reproduce exact quantities? Previous work with speakers of languages that lack number words involved participants only from non-numerate cultures. Deaf Nicaraguan adults all live in a richly numerate culture, but vary in counting ability, allowing us to experimentally differentiate the contribution of these two factors. Thirty deaf and 10 hearing participants performed 11 one-to-one matching and counting tasks. Results suggest that immersion in a numerate culture is not enough to make one fully numerate. A memorized sequence of number symbols is required, though even an unconventional, iconic system is sufficient. Additionally, we find that within a numerate culture, the ability to track precise quantities can be acquired in adulthood.

Keywords

Number; Language and thought; Nicaraguan Sign Language; Sign language

1. Introduction

Computing exact quantities is an essential skill in modern society. In cultures around the world, adults constantly count objects, adding and subtracting with little effort. Nevertheless, in typical development it takes years for children to become competent number users. Exactly what capacities are necessary to track and reproduce exact quantities? In children, a memorized count list appears to play an essential role (Fuson, 1988; Le Corre & Carey, 2007; Wynn, 1990, 1992). But what if such a count list is not present in an individual's native language, even into adulthood? Is experience with cultural uses of number, such as money, or games with dice, sufficient to lay the foundations for numerical cognition if number language is not available?

Research has found that even before young children can talk, they can engage in number reasoning about exact quantities up to three or four (Starkey & Cooper, 1980; Wynn, 1996; Xu & Spelke, 2000). For example, they can keep precise track when one or two objects are added or subtracted from a small set behind a screen. They can also engage in approximate, analog reasoning about large quantities (Dehaene, 1997; Feigenson, Dehaene, & Spelke, 2004; Lipton & Spelke, 2003). However, not until after children have memorized the

sequence “one, two, three, four, five” and upwards can they understand and manipulate exact larger quantities. The role of such counting language in this domain of conceptual development is debated (Carey, 1998; Dehaene, 1997; Gelman & Gallistel, 2004; Wynn, 1990).

In a more recent approach to the puzzle, researchers have turned to speakers of languages that lack number words. The Amazonian Pirahã language has only three words for amounts (Gordon, 2004), and these words do not appear to designate exact quantities (Everett, 2005; Frank, Everett, Fedorenko, & Gibson, 2008). Gordon (2004) found that Pirahã-speakers performed poorly on a variety of numerical matching tasks, and the nature of their errors with quantities greater than three suggested that they were using analog magnitude estimations – the same strategy used by infants, adults prevented from counting, and nonhuman animals (Whalen, Gallistel, & Gelman, 1999). Based on this pattern of performance, Gordon proposed that the Pirahã lack a concept of the exact numerosity of a set. Frank et al. (2008), found that Pirahã-speakers’ performance was impaired specifically in those tasks that precluded the use a strategy of aligning items one-to-one, such as when holding a target quantity in memory. They argued that Pirahã-speakers do not lack understanding of the concept of exact numerosity, but rather lack the culturally learned tool, counting, that allows for representations of exact numerosities. Research with the Mundurukú, another Amazonian group with a limited number vocabulary, found that they are also unable to determine the exact quantity of large sets, and appear to use approximate estimation strategies for numerosities greater than three or four¹ (Pica, Lerner, Izard, & Dehaene, 2004).

An important consideration when interpreting the results of the studies with speakers of innumerate languages is that they also live in largely innumerate cultures. To take the extreme case, the Pirahã do not measure distances, play with dice, or even use money. We therefore cannot know whether their poor performance is due to a lack of language about number, or a lack of experience in situations in which exact quantity is important (see Gelman & Butterworth, 2005). To disentangle these effects, we look to individuals who live in a fully numerate culture, but lack number words: older deaf adults in Nicaragua.

1.1. A history of the Nicaraguan deaf community

The deaf community in Nicaragua, and its sign language, emerged with expanding programs for special education in the 1970s. Before then, deaf people rarely met each other. The establishment of a primary school for special education in 1977, and a vocational school in 1980, brought deaf children and adolescents together in greater numbers than ever before (Polich, 1998, 2005). Although lessons were conducted in Spanish, students gestured freely together, and soon a sign language was born (Kegl, 1994; Senghas, 1997). Nicaraguan Sign Language (NSL) continued to develop yearly, as new children learned it (A. Senghas, 2005; Senghas & Coppola, 2001). What began as gesturing among 50 children has grown into a complex, natural language with over 1000 signers.

Though their primary language community is the deaf community, deaf Nicaraguan adults are not isolated from Nicaraguan culture. Most live with extended non-deaf families, including spouses and children. They have jobs, ride public transportation, and shop at the market. They use money on a daily basis, and often play gambling games with dice and

¹Butterworth, Reeve, Reynolds and Lloyd (2008) failed to find a difference between English-speakers and speakers of the minimally numerate languages Walpiri and Anindilyakwa. However, their participants were children, with poor one-to-one matching performance overall. Presumably the English-speaking children had not yet acquired the abilities that will eventually differentiate them from the other language groups.

cards. In sum, they live normal, acculturated lives in a fully numerate culture, a culture that provides motivation to keep track of large, exact quantities.

1.2. Nicaraguan number signs

As NSL developed, a variety of number signs emerged, eventually converging on a conventionalized set (Katseff & Senghas, 2004). Before 1990, there was variability in the handshapes used. Number signs tended to be highly iconic, with a one-to-one mapping between the number of fingers extended and the value represented (Fig. 1). Under this system, the value *six* is represented by extending six fingers, the value *ten* by extending all ten fingers, and the value *twenty* by signing *ten* twice.

In the early 1990s, number signs underwent rapid standardization, and became one-handed. The new versions are quicker, smaller, and less iconic. Etymological residues of the original forms are evident in the new signs, but there is no longer a one-to-one match between fingers and values (Fig. 2). Under this system, *six* is produced with a rotation of the fist with the thumb extended; *ten*, with a closing movement of the thumb and forefinger; and *twenty*, with a closing of the thumb against the first two fingers.

This history has produced a community with a range of counting systems and counting competence. Whether and how individuals count depends on their age. Today's adolescents learned to count in childhood, using the new one-handed system. Younger adults learned the iconic, two-handed system in childhood, and learned the one-handed system later in life. Older adults, who had already come of age by the late 1970s, learned neither system as children. Some of these individuals eventually learned to count, and some never learned at all. However, all were immersed in the same numerate culture throughout their lives. Thus, deaf Nicaraguans enable us to differentiate the effects of cultural support and counting competence on the ability to mentally track exact numerosity.

2. Methods

2.1. Participants

Forty Nicaraguans participated in the experiment: 10 older deaf adults, 10 young deaf adults, 10 deaf adolescents, and 10 Spanish-speaking hearing adults (Table 1). One additional older adult who failed the Object-Matching screening was excluded from the study.

2.2. Design and procedure

Participants completed 11 tasks administered by the first author, with the assistance of a fluent NSL signer. The stimuli included red gaming tokens of two sizes with the experimenter's and participant's tokens always differing in size. Tasks were administered over one or two sessions in 2005 and 2006.

Object Matching tasks introduced participants to the one-to-one matching procedure, and screened participants for the remainder of the study. These tasks were similar to those used by Gordon (2004).

1. *Row-Row*: The experimenter laid out a row of tokens, and participants were asked to lay out the same number of tokens. The experimenter administered up to four trials, of 2, 9, 5, and 7 tokens each. Once the participant passed two trials in sequence, the experimenter moved on to the next task.
2. *Cluster-Row*: The experimenter laid out a number of tokens in an unstructured cluster, and participants were asked to lay out the same number of tokens. Initially this task included nine trials of quantities between 1 and 13. The first four trials

included the targets 1 through 4, followed by five trials of high targets (5, 6 or 7, 8 or 9, 10 or 11, 12 or 13), in one of four pseudo-random orders. Orders beginning with 1 were avoided, as were linear series of three or more (such as 4, 5, 6). As performance was consistently at ceiling for all but the older adults, this task was reduced in the second year of testing to a maximum of four trials (3, 8, 6, 7) for the other groups. In this shorter version, as in the Row-Row task, once participants passed two trials in sequence, the experimenter moved on to the next task.

Ephemeral Matching tasks involved one-to-one matching of stimuli that did not persist over time. The specific tasks were designed to vary with respect to whether it was the stimulus or the response, or both, that was ephemeral, although ultimately they were combined to form a single Ephemeral measure.

Item orders: Initially, the Cluster-Row, Tap-Tap, Tap-Object, Object-Tap, and Tokens-in-a-Cup tasks were carried out with the four 9-trial orders described above, counter-balanced across subjects and groups. The second year, four new 11-trial orders were created for the Ephemeral Matching tasks. The first four trials included the targets 1 through 4, followed by seven trials of high targets (5, 6, 7, 8, 11, 12, and 13), in one of four pseudo-random orders. For participants who had already completed one session of 9-trial orders, a shorter second session was administered providing the remaining trials needed to elicit all 11 target quantities on each task.

1. *Tap-Tap:* The experimenter tapped some number of times on the participant's knee or upper arm, and the participant tapped the experimenter the same number of times.
2. *Tap-Object:* The experimenter tapped the participant some number of times, and the participant placed that same number of tokens in a row.
3. *Object-Tap:* The experimenter placed some number of tokens in a row, then covered them. The participant tapped the experimenter that same number of times.
4. *Tokens-in-a-Cup:* The experimenter dropped some number of tokens into a cup, one at a time. The participant then dropped the same number of tokens into a cup.

Quantifying tasks required participants to determine the quantity of a set and to represent it with a summary symbol. Here one-to-one mapping was neither a readily available strategy, nor a sufficient response.

1. *How-Many:* The experimenter laid out some number of tokens and asked the participant how many there were. Trials included 3, 4, 1, 2, 7, and 13 tokens.
2. *Give-a-Number:* The experimenter asked the participant to give her some quantity of tokens. In her signed requests, the experimenter used the system of number signs (one- or two-handed) that the participant had used in the How-Many task, briefly presenting the sign and dropping her hands before the response was given. Trials included 2, 4, 1, 7, 3, and 13.
3. *Notes-to-Coins:* The experimenter handed the participant a bag of one-cordoba coins.² For each trial, she placed a monetary note on the table and asked the participant to lay out the same value in coins. Trials included 10-, 50-, 20-, and 100-cordoba notes.

Reciting a Count List Participants were asked to count to 120, or as high as possible.

²Nicaraguan currency, worth approximately US\$0.05.

Writing Numerals Participants were asked to write the Arabic numerals 1–20.

3. Results

3.1. Reciting a Count List

Of the 10 older adults, four were unable to count to 10, using any system. They produced a string of number- and number-like signs, generally between one and five, but after that could not produce number signs in a reliable order. We refer to these four individuals as *noncounters*. Three older adults could count to 10 but not to 100, two counted to 100, and one counted to 120. They usually did not use the conventional system, using two hands for values greater than 5. Three of the more skilled counters mixed in signs from the newer, one-handed system; one used these new signs exclusively. We refer to these six individuals as *late counters*.

Of the 10 younger adults, three could count to 100, and seven could count to 120. All of the younger adults were familiar with the older, two-handed system, but most preferred the newer, one-handed signs, which they had learned in adolescence or adulthood. They occasionally used the two-handed signs when producing number signs in isolation.

All 10 of the adolescents counted to 120 using the conventional one-handed signs. All 10 hearing participants counted to 120 in Spanish without difficulty.

The variation in counting ability between groups observed here allows us to proceed to investigate the role of counting expertise in the ability to track quantity.

3.2. Writing Numerals

There was variability among older adults in Writing Numerals (Fig. 3). Three of the noncounters were unable to write numerals from 1 to 20, and one was able to write these numerals without error. One noncounter (3a) produced strings of curly number-like markings, one (3b) produced a series that lacked 5, 9, 14, 17, and 20, with order errors above 6, and one (3c) produced sequences of the numbers 1–5, with internal repetition of 2 and 5. Of the late counters, one wrote the sequence from 1 to 10 twice, one wrote the numbers 1–20 with the units and tens columns reversed (21, 31, 41, etc.), and one wrote the numbers correctly but omitted the number 7. The remaining four older adults wrote the numbers without errors, as did all of the younger adult (3d), adolescent (3e), and hearing participants.

Evidently, lifelong immersion in a culture with written symbols for number is not sufficient for an individual to learn those symbols. As in the recitation of a count list, the poorest mastery of written numerals was observed among the older adults. However, performance on the two tasks was not exactly matched, and one individual had mastered written numerals without being able to produce a recitable count list.

3.3. Object Matching tasks

1. *Row–Row*: Performance was high overall on the Row–Row Matching task. The majority of participants required only two trials to pass this screening, including one older adult noncounter. Six participants made exactly one error in which they were off by one token. These included one older adult noncounter, two older adult late counters, one younger adult, one adolescent, and one hearing participant. Two noncounters missed two items before passing two. By the end of this task, all retained participants clearly understood the one-to-one matching procedure. The one participant who was eliminated from the study never understood that the goal of the task was to match the target number of tokens.

2. *Cluster-Row*: The younger adults, adolescents, and hearing participants, who received the short version of the Cluster-Row task, again had good performance. Two adolescents made a single error each in which they were off by one token.

The older adults were not at ceiling, and received a longer version of the Cluster-Row task. Fig. 4 gives the accuracy, defined as proportion of correct trials, of older adults separated by counting ability. For both older adult noncounters and older adult late counters, performance was perfect on targets up to six. For numerosities of six and higher, responses differed from the target by a mean of 4.6% of the target value, with noncounters at 6.3% and late counters at 3.7%.

There are at least two conceivable strategies for solving this task. One is to count the tokens, as they are being placed on the table, or after the set is complete. The other is to attend to each target token in turn, placing a token on the table for each, thereby creating a one-to-one mapping. In most cases, it was not possible to determine the strategy being applied, since there was no external behavior to observe. However, some of the counters did exhibit behaviors that suggested that they were counting, such as touching each of the tokens, and one late counter exhibited an observable one-to-one mapping strategy, placing a token next to each token of the target set. Presumably counters have both strategies available, while noncounters have only one-to-one mapping. As Fig. 4 shows, even those older adults who had both strategies available, the late counters, made errors for target values greater than six.

3.4. Ephemeral Matching tasks

Four Ephemeral Matching tasks required participants to track the numerosity of non-persisting stimuli: Tap-Tap, Tap-Object, Object-Tap, and Tokens-in-a-Cup. Overall accuracy on the Ephemeral tasks was .77 ($SD = .23$; see Table 2). An ANOVA was conducted on accuracy in the Ephemeral tasks, with group (4) as a between-subjects variable and task (4) as a within-subjects variable. There was a significant difference between groups, $F(3, 34) = 12.37, p < .0001$. Post-hoc pairwise comparisons revealed that the older adults had lower accuracy than each of the other groups (all p s $< .04$ with Bonferroni adjustment); the other groups did not differ significantly from each other. There was also a main effect of task, $F(3, 102) = 8.80, p < .0001$. Pairwise comparisons revealed that the Tap-Tap task yielded lower accuracy than each of the other tasks (all p s $< .004$). This pattern held for all groups. There was no interaction found between group and task.

The relevance of counting ability is most evident when we consider the performance by individual (Fig. 5). First, the five individuals who had the most difficulty with the Ephemeral tasks include all four noncounters and one late counter. Evidently, one cannot succeed at these tasks without a memorized count list. Second, the individuals who exhibited the best performance, with at least 90% accuracy, include counters from all four groups. Evidently, success at tracking ephemeral events is possible throughout the range of counting experience and counting systems that we documented, though other factors must certainly contribute to performance.

Next, we consider whether errors on the Ephemeral tasks are limited to target values outside the range of success in the Object Matching tasks. Recall that even the older adult noncounters had perfect performance at one-to one matching for target values of six and below. Fig. 6 presents the accuracy for each target value on the Ephemeral tasks. In this case, errors occur at even the lowest targets, particularly among the noncounters. Therefore, one-to one matching ability is not sufficient to track transient events.

Low accuracy rates on the Ephemeral tasks correspond to a large magnitude of error. For numerosities of six and higher, responses differed from the target by a mean of 9.6% of the

target value, with older adult noncounters at 25.9%, older adult late counters at 9.5%, younger adults at 7.1%, adolescents at 4.8%, and hearing participants at 0.9%.

The error relative to the estimated numerosity is typically tracked with the *coefficient of variation*, computed as the SD/mean. The four groups differed significantly in overall coefficient of variation, $F(3, 36) = 8.23$, $p < .001$; in pairwise comparisons older adults presented a significantly higher coefficient of variation than each of the other groups (all p s $< .05$ with Bonferroni adjustment).

Across targets, a flat coefficient of variation is generally taken to indicate the use of an analog estimation strategy for assessing magnitude (Barth, Kanwisher, & Spelke, 2003; Whalen et al., 1999), rather than the use of a counting or another one-to-one matching strategy. In order to determine whether the coefficient of variation changed across target values, we considered targets of six and greater, combining them into *medium* (6, 7, and 8) and *high* (11, 12, and 13) target values. An ANOVA was conducted with group (4) as a between-subjects variable and target value (2; medium vs. high) as a within-subjects variable. This analysis revealed a significant overall effect of target value, $F(3, 36) = 6.18$, $p < .02$; that is, the coefficient of variation increased with target value for targets of six and greater. There was also a significant main effect of group, $F(3, 36) = 8.34$, $p < .0001$. There was no interaction between target value and group. Thus, the coefficient of variation is rising slightly across targets, with parallel slopes over the groups (Fig. 7).

The rising coefficient of variation seen for all groups on the Ephemeral tasks indicates that none were using an exclusively analog strategy across target values. As participants were required to track larger ephemeral targets, even those who could count occasionally lost track. Frank et al. (2008) suggest that a small but positive slope in the coefficient of variation can result from a mixed strategy in which participants initially apply an error-prone exact matching strategy, falling back on an analog strategy when one-to-one enumeration fails. Such strategies, successfully used by some participants to match low target values, may have yielded more errors at high target values.

As we attempt to determine the strategies used in the Ephemeral tasks, it is clear that the ability to produce a count list is essential. No individual without such a list succeeded. One can imagine solutions to this task that do not require a count list, for example, extending a finger for each tap received, and then retracting a finger with each tap produced,³ but we did not observe such strategies, perhaps because the two manual activities would have interfered with each other. All participants found ephemeral stimuli to be more difficult to track than concrete objects, and several commented on this explicitly. Many counted “out-loud” with their hands, rather than counting “silently” in their heads. Such signed counting is evidently different from using the fingers as external objects for one-to-one mapping; indeed, the two uses of the hands are in competition. We observed this kind of interference in the strategy employed by the older adult counter who had the most difficulty with the Ephemeral tasks. He extended a finger with each shoulder tap, and then attempted to count how many fingers he had extended. With his fingers already occupied, he made errors counting. Nevertheless, his strategy displays the conceptual elements for determining exact quantity, including assigning a unique symbol to each element to be counted, and identifying the quantity of the set as the value of the last-mentioned symbol.

³We are grateful to an anonymous reviewer for this example of a non-counting strategy.

3.5. Quantifying tasks

Three Quantifying tasks required participants to determine the quantity of a set: How-Many, Give-a-Number, and Notes-to-Coins. Specifically, these tasks entailed producing or interpreting a summary representation, such as a signed number or a written numeral, for large and small sets. The question was whether the ability to use such representations requires a recitable count list. Accuracy rates by task and group are given in Table 3, with the older adults separated into noncounters and late counters. No significant differences in accuracy were found between groups on any of these tasks (How-Many $F(3, 36) = 2.09$, $p = .12$; Give-a-Number $F(3, 36) = 1.46$, $p = .24$; Notes-to-Coins $F(3, 34) = 1.69$, $p = .19$).

The first two Quantifying tasks, How-Many and Give-a-Number, included four low target values (1–4) and two high target values (7 and 13). As can be seen in Fig. 8, participants from all groups performed at ceiling on low target values. Older adult noncounters begin to fail at targets of 4 on both tasks. On How-Many, some older adult late counters, younger adults, and adolescents failed at the high target values, 7 and 13, and one hearing adult failed at 13. On Give-a-Number, two younger adults and one hearing participant failed on 13, and older adult late counters and adolescents had errorless performance.

Notes-to-Coins tested higher values: 10, 20, 50, and 100. Hearing participants had nearly error-free performance (one participant made an error on 10). For the remaining groups, there were one or two very poor performers in each group who accounted for the majority of errors. Errors, when they occurred, tended to be large: inaccurate responses deviated from the target value by a mean of 26%.

This variability in performance in the Notes-to-Coins task suggests that counting ability alone is not sufficient for success. Counting can be error-prone, and one-to-one matching is not an available strategy when the target value is symbolically represented, as is a numeral on a currency bill. Observed strategies included grouping coins into smaller subsets of five or 10, and lining coins up in rows. By arranging the objects spatially, participants can avoid having to count up to numbers higher than 10, for example, by creating a 10 by 10 grid. Strategies such as these, when used in combination with counting, are clearly helpful in producing and checking one's response.

The three older adult noncounters who completed the Notes-to-Coins task showed three distinct response patterns. One noncounter, the one who could write the numerals 1–20, had perfect performance on this task. Another, the participant who wrote only the numerals 1–5 with repetitions (Fig. 3c), failed at all four target values, giving 18 and then 12 coins for the 10-cordoba note, 22 coins for the 20-cordoba note, 26 coins for the 50-cordoba note, and 158 coins (the entire set available) for the 100-cordoba note. The third noncounter, who produced non-numeral markings (Fig. 3a), succeeded with targets 10 and 20, but inaccurately gave 45 coins for a 50-cordoba note and 30 coins for a 100-cordoba note.

The results from the three Quantifying tasks indicate that a recitable count list is a highly effective tool to determine the quantity in a set. It may well be the best tool, though one may succeed by other means, even when assessing the cardinality of sets as high as 20 or 100. Alternate or additional strategies such as grouping or recounting also contribute to success. Of course, such strategies are best used in conjunction with a count list. The iconicity or opacity of the count list, however, does not seem to modulate its effectiveness.

4. Discussion

Deaf Nicaraguan signers have provided a rare opportunity to tease apart the effects of language and cultural environment on numerical cognition. The variation in counting skills

found among our Nicaraguan groups allows us to investigate the role of a memorized, recitable count list, in particular, in the ability to track and represent exact quantities. Due to their deafness, and their lack of exposure to a developed sign language early in life, some adults who live in a richly numerate culture (and show no evidence of a congenital cognitive impairment) never learned to produce a counting sequence such as “one, two, three, four...”. Others initially learned a highly iconic system, with a one-to-one correspondence between the manual symbol (the number of fingers extended) and the value represented; and yet others learned a more opaque sequence of number symbols from the outset. What effect does one’s counting system, or lack thereof, have on fundamental aspects of numeracy, including the ability to (a) match objects one-to-one, (b) understand that a set has a single, cardinal value, (c) determine the cardinal value of a set of persisting or ephemeral elements, and (d) produce or interpret a symbol for an exact quantity?

Both counters and noncounters were able to match concrete objects one-to-one when they were able to align them. When this strategy was less available, as in the Cluster-Row task, all participants could still succeed when there were six or fewer objects to be matched. However, noncounters and late counters experienced some difficulty as the number of objects to be matched increased beyond six. Evidently, matching the quantity of a larger persisting set of objects can be aided by a count list, though the task can be completed successfully without it.

However, to quantify ephemeral stimuli, such as taps on the shoulder, a count list is apparently necessary. In this case, there are no physical objects to align. To successfully track such stimuli, one must produce an invariant counting sequence, mentally matching a word to each event. On our Ephemeral tasks, the participants who could not recite a count list made errors on even small quantities.

Counting can also be applied successfully in tasks requiring one to produce or interpret symbols for particular quantities, particularly when combined with other strategies. Nevertheless, some individuals can produce and interpret symbols representing large quantities (such as 20 or even 100) without being able to recite a count list.

One older adult noncounter was able to write the numerals from 1 to 20 and performed well on tasks in which the quantity to be matched persisted over time. He could even accurately give 100 coins for a 100-cordoba note. However, this same individual performed no better in the Ephemeral Matching tasks than did the other older adult noncounters. On the Tap–Tap task, in which both the stimulus and the response were ephemeral, he showed the poorest performance of the group. This pattern of performance suggests that numeral-writing ability is not a sufficient tool to mentally track the exact quantity of ephemeral events. One must have a memorized count list, that must be mentally recitable.

On all tasks, the hearing participants tended to be the best performers. They had more educational experience than our deaf participants, which may have given them explicit access to strategies like grouping, and more practice with counting, resulting in fewer errors. In addition, because they spoke their number words instead of signing them, they may have faced less interference in our manual tasks. For our deaf participants, using the hands to tap and to manipulate tokens may have interfered with the manual motor activity associated with reciting a count list, even mentally, much the way verbal shadowing can interfere with spoken counting.

Even where their performance was error-prone, our participants differed from children who can quantify only two or three objects. A child “three-knower” will hand over handfuls of objects when asked for any quantity over three, rather than increasing the response relative to the targeted amount (Wynn, 1990). Our participants, in contrast, produced higher guesses

for higher targets. Furthermore, our participants' patterns of performance were often specific to the task. Their ability to succeed at a given target value in one task and not another may reflect an understanding of some, but not all, of the concepts in question, or an uneven application of knowledge. Unlike children, these adults have developed effective strategies in response to the demands of their numerate culture. For example, one of the older adult participants whose writing included no numeral-like symbols and who could not recite a count list even to five could nevertheless successfully give 10 and 20 coins for corresponding monetary notes. An adult non-counter is not a child "pre-counter."

What do these results reveal about the role of a counting sequence in the development of enumeration? Typically, children memorize the count list early, well before they use it to assess the cardinal value of a set (Le Corre & Carey, 2007; Wynn, 1990). Wynn (1990) proposed that after young children have learned to map the quantities one, two, and three to number words, they have an insight that links this short sequence, one-to-one, to the beginning of a longer, already memorized count list. With this insight, children discover counting, which they can then apply to quantifying higher numerosities. Our adult noncounters never had this experience. When they learned the principle of one-to-one mapping, they had no previously memorized count list to link it to. We suggest that as a result, some never developed representations of exact numerosities, while others learned to quantify higher numerosities by some other route. Whatever their other route, it left them without a means of tracking transient elements. This does not mean that they fail to understand that there is some exact, cardinal value for the set. Indeed, participants from all groups frequently indicated when they lost track on Ephemeral tasks, usually after four or five, reported that they were guessing and uncertain, and asked if they had gotten the answer correct. They also asked if they needed to produce another tap, or take away a token. Such behaviors suggest that they knew we had a specific quantity in mind.

Among those who learned a counting sequence in childhood, there is no apparent significant effect of having learned an iconic system first, or of acquiring a new, less-iconic system later, in adulthood. The younger adults, who used a two-handed, ten-fingered counting system as children, were not significantly worse at tracking quantities than adolescents, who have used a less-iconic, one-handed system all their lives. If there is a difference, it is a subtle one, and both systems clearly make use of discrete symbols for discrete quantities. That is, holding up six fingers represents the concept *six*, not just six units of one. Equally symbolic is the more opaque sign for *six* – holding up a thumb. Either will serve as a number word, as long as it is part of a memorized sequence.

Furthermore, there are individuals in every group of counters (even some older adults) who perform at ceiling on every task. What is essential, then, is a recitable counting sequence, learned at some point in one's lifetime. Those participants who learned number signs in adulthood – the older adult late counters – can succeed at tracking ephemeral quantities, although they are more error-prone than those who learned a counting sequence in childhood. With a lifetime of numerate culture as support, one can learn to count late in life.

Our findings are clear: living in a numerate culture is not necessarily enough to make an individual numerate. Adults who lack a recitable list of number words are unable to accurately quantify stimuli presented to them in a sequence. Nevertheless, some adults without a recitable count list can assess and represent the exact cardinal value of large sets in certain situations. This finding has implications for all aspects of number understanding proposed to follow from counting routines, such as the concepts of unique successors, stable ordering, and conservation of number (Le Corre & Carey, 2007). It would be worthwhile to explore whether the noncounters have been able to develop these other concepts, perhaps by

alternative routes. The memorized, mentally recitable count sequence, that for most of us served as the gateway to an understanding of number, may not be the only way to get there.

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Fig. 1. Nicaraguan number signs before 1990: (a) The sign for *six* and (b) The sign for *ten*.

Fig. 2.
Nicaraguan number signs after 1990: (a) The sign for *s'ix* and (b) The sign for *ten*.

Fig. 3. Samples of writing by participants asked to write the numbers 1–20: (a–c) older adult noncounters; (d) a young adult; (e) an adolescent.

Fig. 4.
Older deaf adults' accuracy on the Cluster-Row task, for each target value.

Fig. 5.

Accuracy on Ephemeral tasks by group and individual. For older adults, noncounters and late counters are separated. Each point represents an individual participant; horizontal bars indicate group means.

Fig. 6. Accuracy on Ephemeral tasks by target, by group. For older adults, noncounters and late counters are separated.

Fig. 7.
Coefficient of variation on Ephemeral tasks, by target value, for each group. For older adults, noncounters and late counters are separated.

Fig. 8. Accuracy on How-Many, Give-a-Number, and Notes-to-Coins, by target value, for each group. For older adults, noncounters and late counters are separated.

Table 1

Participant demographics.

Group	n	Age in years		Date of entry into deaf community	
		M	SD	M	SD
Older deaf adults	10 ^a	41.4	9.0	N/A	N/A
Young deaf adults	10	29.9	4.4	1981	3.4
Deaf adolescents	10	19.5	2.6	1991	1.9
Hearing adults	10	44.3	11.6	N/A	N/A

^aTwo of the older deaf adults (a noncounter and a late counter) did not complete two of the 11 tasks: Tokens-in-a-Cup and Notes-to-Coins.

Table 2

Accuracy rates for Ephemeral tasks, by group. For older adults, noncounters and late counters are reported separately. (One noncounter and one late counter did not perform Tokens-in-a-Cup.)

Group	n	Tap-Tap	Tap-Object	Object-Tap	Tokens-in-a-Cup
Older adult noncounters	4	0.27	0.31	0.44	0.55
Older adult late counters	6	0.53	0.79	0.63	0.67
Young adults	10	0.70	0.74	0.80	0.81
Adolescents	10	0.76	0.80	0.86	0.85
Hearing	10	0.90	0.98	1.00	0.94

Table 3

Accuracy rates for Quantifying tasks, by group. For older adults, noncounters and late counters are reported separately. (One noncounter and one late counter did not perform Notes-to-Coins.)

Group	<i>n</i>	How-Many	Give-a-Number	Notes-to-Coins
Older adult noncounters	4	0.83	0.85	0.50
Older adult late counters	6	0.91	1.00	0.90
Young adults	10	0.88	0.95	0.75
Adolescents	10	0.94	1.00	0.83
Hearing	10	0.98	0.99	0.98