Learning to count begins in infancy: evidence from 18 month olds’ visual preferences

Virginia Slaughter1,*, Shoji Itakura2, Aya Kutsuki2 and Michael Siegal3

1Early Cognitive Development Centre, School of Psychology, University of Queensland, Brisbane 4072, Australia
2Department of Psychology, Graduate School of Letters, Kyoto University, Yoshida-Hommachi, Sakyo-ku, Kyoto 606-8501, Japan
3Department of Psychology, University of Sheffield, Western Bank, Sheffield S10 2TP, UK

We used a preferential looking paradigm to evaluate infants’ preferences for correct versus incorrect counting. Infants viewed a video depicting six fish. In the correct counting sequence, a hand pointed to each fish in turn, accompanied by verbal counting up to six. In the incorrect counting sequence, the hand moved between two of the six fish while there was still verbal counting to six, thereby violating the one-to-one correspondence principle of correct counting. Experiment 1 showed that Australian 18 month olds, but not 15 month olds, significantly preferred to watch the correct counting sequence. In experiment 2, Australian infants’ preference for correct counting disappeared when the count words were replaced by beeps or by Japanese count words. In experiment 3, Japanese 18 month olds significantly preferred the correct counting video only when counting was in Japanese. These results show that infants start to acquire the abstract principles governing correct counting prior to producing any counting behaviour.

Keywords: counting; one-to-one correspondence; infancy; preferential looking

1. INTRODUCTION

Children begin to count some time after age 2 and their skill develops over the next several years [1–3]. But before then, infants witness many instances of counting demonstrated by parents and older siblings, or portrayed on television. What, if anything, do very young children glean from this early exposure to counting?

Accurate counting adheres to three abstract principles: (i) one-to-one correspondence between count words and objects being counted, (ii) stable ordering of the count words, and (iii) cardinality in that the last count word in a sequence represents the total number counted. Gelman & Gallistel [2] proposed that these principles guide children’s learning of their counting routine, and so are implicitly understood before children master counting. An alternative view is that the how-to-count principles are acquired in conjunction with, or after, children master a count routine [4–7].

Evidence for the alternative view comes from experiments showing that some children who can accurately count a small set of objects may still fail to understand the cardinality principle. This principle is typically mastered last [1] and it is crucial because it is specific to number representations (whereas one-to-one correspondence and stable order can also apply to non-numerical systems). Wynn [3,10] tested 2 and 3 year old children on a ‘give-a-number’ task, in which they were asked to extract between one and five objects from a larger set. Although all of the children were capable of producing a count routine, their performance on this task varied. One-knowers could accurately extract one object but failed with higher numbers, and so on. Children who accurately extracted subsets of all numerosities were deemed cardinal principle-knowers (CP-knowers). In a longitudinal study, Wynn [3] showed that it took approximately 1 year for children to progress through the and their count words. Some young children use unconventional count words, but they do so in a consistent stable order (e.g. 1, 2, 10). Gelman & Gallistel [2] also observed that many children adhere to the cardinality principle by repeating the final word of their count when reporting how many in the set, but this finding has not always been replicated (e.g. [7–9]). Based on their observations, Gelman & Gallistel [2, p. 204] proposed that ‘knowledge of counting principles forms the basis for the acquisition of counting skill’. They also suggested that this knowledge may be acquired via generative rules, akin to the rules of grammar.

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‘knower’ stages, suggesting that understanding of the CP was acquired only gradually, and independently of children’s being able to produce counting behaviour. Wynn also showed that CP-knowers performed well on a variety of counting tasks, whereas the other children made errors indicative of their knower-level (see also [6] and [11]). This evidence suggests that the abstract how-to-count principles are acquired in conjunction with, or following, mastery of the first few number terms in the counting routine.

Another approach to the question of whether how-to-count principles are understood prior to, or as a result of, learning to count, is to assess children’s detection of counting errors. Gelman & Meck [12] reasoned that identifying someone else’s counting errors should be easier for young children than generating an accurate count since, in the former case, they only need monitor adherence to the how-to-count principles whereas in the latter case, they also have to manage the memory, motor and language requirements of counting behaviour. Across three studies, Gelman & Meck [12] found that 3 and 4 year olds who were only capable of accurately counting small sets recognized violations of all three how-to-count principles made by a puppet counting large sets. These results support the view that recognition of the how-to-count principles precedes counting skill (see also [13]). However, other reports suggest that counting error detection develops alongside counting skill in 3–5 year olds [6,8,9].

To date, the evidence on both sides of the debate has come from studies of children who have already begun to produce some counting behaviour and they have all required an explicit verbal or manual response. In the current study, we used a non-verbal visual preference test to investigate whether or not infants are sensitive to the one-to-one correspondence principle in the context of counting events. We adopted an error detection approach and measured infants’ attention to videos of correct (principle-consistent) and incorrect (principle-inconsistent) counting events.

We reasoned that implicit recognition of the one-to-one principle would be evident if infants visually discriminated between principle-consistent and principle-inconsistent counting sequences by looking longer at one or the other. We predicted a preference for the correct counting sequence because this event would be more familiar and infants tend to prefer the familiar when the test stimuli are relatively complex [14]. We tested 15 and 18 month olds because the earliest age at which children begin to produce counting behaviour is 2 years [1,3,6]. Therefore, infants in the current study were at least six months from producing a counting routine.

2. EXPERIMENT 1
(a) Participants
Thirty-six Australian infants participated. These included eighteen 15 month olds (10 boys) ranging in age from 15 months 0 days to 16 months 0 days, and eighteen 18 month olds (nine boys) ranging from 17 months 15 days to 18 months 27 days.

(b) Material and methods
Infants sat in a high chair positioned 50 cm in front of a widescreen monitor surrounded by a black curtain so that only the screen was visible. A video camera was set up behind the curtain with its lens unobtrusively protruding through so that the infant’s head and shoulders were captured on film throughout the experiment. Parents sat in a chair next to their infants but facing away from the screen. They were instructed to interact with their infants only if they needed comforting.

The infants watched a 3 min video that began with a static display showing six differently coloured fish stickers arranged in two rows of three (one above the other) on a light background. A female voice said ‘Look at the fish!’ and then a woman’s hand with just the index finger outstretched moved onto the screen and pointed to the fish while the same female voice recited the count terms from ‘one’ to ‘six’. In the correct count condition, the hand pointed to each of the fish in one row and then pointed to each of the fish in the next row, so that all six fish were counted. In the incorrect count condition, the hand alternately pointed up and down to the two left-most or the two right-most fish (depending on the side from which the hand appeared) while the voice counted to six. Different hands and voices were used in the two conditions.

The count sequences were presented in four blocks. In each block, the correct count was shown twice and the incorrect count shown twice. Between presentation blocks, a brief display of fluttering butterflies was presented. Whether the pointing hand came into the screen from the right or the left side, and whether it started on the top or bottom row, was counterbalanced across blocks. The order of the counting events (correct versus incorrect first) was counterbalanced across infants.

Parents reported how many days per week they demonstrated counting to their infants, e.g. in book reading, a game or any other context. This information was not collected for seven of the 18 month old infants owing to experimenter error.

(c) Results and discussion
Infants’ looking at the screen was coded from the videotapes by a trained research assistant. Nine infants (25% of the sample) were coded by a second research assistant. The intra-class correlation coefficient for the two sets of looking times was 0.97, indicating excellent agreement.

We analysed infants’ looking at the correct and incorrect count sequences by presentation block, under the assumption that one or more viewings of the two types of count sequences might be required before infants begin to associate the individual female voice with the accuracy of the counting. We also anticipated the potential for fatigue effects over four blocks. Looking times were summarized for each of the four presentation blocks by subtracting the total time (in seconds) infants looked at the incorrect count sequences from the total looking time to the correct count sequences. A looking score greater than zero, therefore, represents a preference for correct counting.

To determine whether infants had a preference for correct counting, we computed a 2 (age group: 15 versus 18 months) × 4 (presentation block: 1, 2, 3, 4) mixed-model ANOVA on the dependent variable looking score. This analysis yielded a significant main effect of age group, $F_{1,34} = 4.28$, $p = 0.046$; $\eta^2_p = 0.11$, indicating that the
15 and 18 month olds differed in their looking preferences. There was no effect of presentation block on looking scores. We then collapsed across blocks to compute follow-up tests on looking scores by age group. One-sample \(t\)-tests revealed that among 18 month olds, looking scores were significantly greater than zero, indicating a reliable preference for correct counting, \(t(17) = 4.25, p = 0.001\). Looking scores for the 15 month olds did not differ from zero, \(t(17) = 0.79, p = 0.44\). (See figure 1 for 18 month olds’ looking scores in experiments 1 and 2).

Table 1 displays the mean looking times, collapsed across block, by age group. We confirmed this data pattern with non-parametric analyses. Among the 15 month olds, 10 of the 18 infants looked longer at the correct counting events; this is not significantly different from chance, \(p = 0.82\) (two-tailed binomial test). By contrast, among the 18 month olds, 14 of the 18 infants looked longer at the correct count events and this proportion is significantly different from chance, \(p = 0.03\) (two-tailed).

The results indicate that 18 month old infants preferred to watch the correct counting events, but that 15 month olds did not have a preference. There is more than one interpretation for this finding. The simplest one is that the older infants found the visual form of the correct counting sequence more interesting than that of the incorrect count, perhaps because the hand moved over a larger portion of the screen. Another interpretation is that 18 month olds generally prefer events that exhibit one-to-one correspondence, but do not recognize their relevance to counting. To explore these possibilities, we included a control condition in experiment 2 in which the displays were identical but the counting voices were replaced by computer-generated beeps.

Another interpretation is that 18 month old infants prefer the correct counting sequence because it conforms to their expectations about counting. This view assumes that, by 18 months, infants have witnessed sufficient counting events to have extracted the one-to-one principle that each item must be tagged only once when counting a set. There was some support for this idea in our data. We correlated the number of days per week parents reported that they counted with their infants (range = 0–7) and infants’ summed looking times to the correct count events. We assumed that looking at the correct counting events reflected infants’ interest in, and perhaps familiarity with, counting. Thus, we predicted a positive association between looking time and number of days that infants were exposed to counting. We ran this analysis on the whole sample (including both 15 and 18 month olds for whom we had data on weekly exposure to counting). The association was significant, Pearson’s \(r(30) = 0.33, p = 0.033\) (one-tailed).

An important follow-on question to this latter finding concerns the specificity of children’s exposure to counting. It may be that the abstract form of counting events, with each object being touched while unique verbal labels are pronounced in the characteristic counting intonation, is sufficient to engage 18 month olds’ preferences for correct counting. Alternatively, it may be that they prefer principle-consistent counting only when it is presented in their own familiar language. Therefore, in experiment 2, we also ran a new condition in which the verbal count was in Japanese.

3. EXPERIMENT 2

(a) Participants
A new sample of 36 Australian 18 month olds (22 boys), ranging from 17 months 15 days to 18 months 13 days old, tested was randomly assigned to the control condition \((n = 18)\) or to the Japanese language condition \((n = 18)\).

(b) Material and methods
The videos were identical to those presented in experiment 1 save for the audio track. In the control condition, the English count words were replaced by computer-generated beeping sounds. The pitch of the beeping sounds differed across the correct and incorrect counting events, to parallel the two different voices in the original display. In the Japanese language condition, the English count terms were replaced by the common Japanese count terms: \(ichi, ni, san, shi, go, roku\) that are normally written and read horizontally as in English. These were uttered using the standard one-syllable pronunciation \((each\ for\ ichi\ and\ rock\ for\ roku)\).

(c) Results and discussion
The looking behaviour of nine infants (25% of this sample) was coded by a second research assistant for reliability. The intra-class correlation coefficient for the two coders’ looking time data was 0.97.

We computed a 3 (condition: control, Japanese language, English language) \(\times\) 4 (presentation block) mixed-model ANOVA on infants’ looking scores. The English language looking scores were those collected in experiment 1. There was a significant main effect of condition, \(F_{2,51} = 4.08, p = 0.023\), \(\eta^2_p = 0.14\), indicating that 18 month old infants’ preferences for correct counting differed by condition. Follow-up one-sample \(t\)-tests collapsing across block indicated that only in the English language condition did infants show a preference for the correct count sequences (table 1).

Since infants did not look longer at the correct count sequences when the English count terms were replaced...
by computer-generated beeps or by Japanese count terms, the results of experiment 2 rule out the possibility that the 18 month olds’ preference for correct counting was driven by low-level visual features of the display or by a general preference for one-to-one correspondence events. Rather, our findings support the position that exposure to language-specific counting events is linked to infants’ preferences for correct counting sequences. Among Australian infants, counting in Japanese disrupted their preferential attention to correct counting. The act of pointing to each fish in turn while a set of unique lexical items from Japanese was voiced in the familiar counting intonation was not sufficient to produce the looking preference. The familiar English lexical items were required for infants to demonstrate their recognition of the one-to-one correspondence principle. However, a cross-cultural comparison is needed as it is possible that some specific feature of the Japanese count terms disrupted the Australian infants’ preferential looking. Therefore, in order to confirm that 18 month olds prefer correct count sequences only when they are familiar (e.g. presented in their native language), we carried out a third experiment in Japan.

4. EXPERIMENT 3
(a) Participants
Thirty-six Japanese infants (21 boys) ranging in age from 17 months 12 days to 18 months 16 days were tested in the English language (\(n = 18\)) and Japanese language (\(n = 18\)) conditions from the previous experiment. An additional two infants were tested but their data were discarded because their looking at both counting events was at the ceiling across all presentation blocks.

(b) Material and methods
The English and Japanese language count sequence videos were identical to those used in the previous experiments. The one alteration was that in this experiment, the introductory statement, ‘Look at the fish’ was spoken in Japanese.

The experimental procedure closely paralleled the previous two experiments, except that the Japanese infants sat on their mothers’ laps instead of in a high chair while watching the videos. Mothers sat quietly and avoided communicating with their infants during the video displays.

(c) Results and discussion
A second research assistant coded the looking behaviour of 8 infants (22% of this sample) for reliability. The intra-class correlation coefficient for agreement between the two coders was 0.97.

To investigate the role of language familiarity on 18 month olds’ preference for correct counting, we computed a 2 (nationality: Japanese versus Australian language) \(\times\) 2 (language: Japanese versus English) \(\times\) 4 (block) mixed-model ANOVA on infants’ looking scores. The looking scores for the Australian infants were taken from the English and Japanese language conditions collected previously. There was a main effect for nationality, \(F_{1,68} = 4.47, p = 0.038\), indicating that the Australian infants had stronger looking preferences. There was also a nationality \(\times\) condition interaction, \(F_{2,66} = 6.36, p = 0.014\), reflecting the fact that Australian and Japanese infants’ looking preferences varied by language condition. These effects were subsumed under a significant three-way nationality \(\times\) language condition \(\times\) block interaction, \(F_{3,204} = 3.10, p = 0.028\), illustrated in figure 2. Australian and Japanese infants had different looking preferences in the language conditions, but only on some of the presentation blocks.

Follow-up tests by block indicated that on the third presentation (block 3) of correct and incorrect counting sequences, Australian infants had a significant preference for the correct count sequences if they were spoken in English, and Japanese infants had a significant preference for the correct count sequences if they were spoken in Japanese. For the Japanese infants, block 3 mean looking to the correct count sequences in Japanese was 8.57 s (s.d. = 1.74) and to the incorrect count sequences, 7.36 s (s.d. = 2.76), indicating a significant preference for correct counting, \(t(17) = 2.59, p = 0.019\). In the English language condition, Japanese infants had no preference: they watched the correct count sequences for an average of 9.40 s (s.d. = 1.12 s) versus 9.54 s (s.d. = 0.74 s) for the incorrect sequences.

Non-parametric analyses of infants’ looking preferences in block 3 confirmed these results. When spoken in Japanese, 15 of 18 Japanese infants preferred the correct count sequences in Japanese (\(p = 0.008\); two-tailed binomial test) but when counting was in English, only 7 of the 18 Japanese infants looked longer at the correct counting event (\(p = 0.48\), two-tailed).

Our results suggest that by 18 months of age, infants have sufficient experience with their cultural counting routine to discriminate between correct counting and incorrect counting that violates the one-to-one correspondence principle. The preference for correct counting sequences in the native language was weaker in Japanese infants when compared with Australian infants; it was only evident on the third presentation block. It is notable, however, that the third block was also where the Australian infants showed the strongest preference. A combination of novelty and fatigue effects may have obscured the preference for correct counting in the early blocks and in the last block. Also the

Table 1. Looking times (in seconds) at correct (adhering to one-to-one correspondence) and incorrect (violating one-to-one correspondence) counting sequences in experiments 1 and 2. Looking times are averaged across presentation blocks.

<table>
<thead>
<tr>
<th>experiment</th>
<th>condition</th>
<th>age group</th>
<th>correct counting sequence</th>
<th>incorrect counting sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>English counting</td>
<td>15 months</td>
<td>8.04 (s.d. = 1.66) *</td>
<td>7.83 (s.d. = 2.17) *</td>
</tr>
<tr>
<td>1</td>
<td>English counting</td>
<td>18 months</td>
<td>8.21 (s.d. = 1.54) *</td>
<td>7.27 (s.d. = 1.37) *</td>
</tr>
<tr>
<td>2</td>
<td>control (beeps)</td>
<td>18 months</td>
<td>8.59 (s.d. = 1.24) *</td>
<td>8.40 (s.d. = 1.07) *</td>
</tr>
<tr>
<td>2</td>
<td>Japanese counting</td>
<td>18 months</td>
<td>7.93 (s.d. = 1.39) *</td>
<td>7.71 (s.d. = 1.73) *</td>
</tr>
</tbody>
</table>

*Statistically significant difference.
Japanese parents reported that they counted objects with their infants an average of 2.58 times each week (s.d. = 3.12), whereas the Australian parents reported an average of 6.07 shared counting experiences per week (s.d. = 1.77). This is a significant difference, \( r(63) = 5.36, p < 0.001 \), indicating that the Japanese 18 month olds generally had less exposure to counting than their Australian counterparts. Following experiment 1, we correlated Japanese infants’ weekly counting experience with their attention to the correct counting sequences (in Japanese) but this revealed no association, \( r(16) < 0.10 \).

Note that the cultural difference in exposure to counting is specific to enumerating objects; Japanese parents reported that their infants were exposed to counting as part of the nightly bath routine, but that bath counting involves reciting the numbers in sequence to mark time-passing, rather than enumerating objects as in the videos we presented.

5. GENERAL DISCUSSION

In these experiments, 18 month olds chose to look longer at counting events that obeyed the one-to-one correspondence principle compared with counting events that violated the principle. This preference cannot be attributed to low-level perceptual differences between principle-consistent and principle-inconsistent displays or to a general preference for events exhibiting one-to-one correspondence since replacing the count words with meaningless beeps or with count words from a different language eliminated it.

An alternative explanation is that infants at 18 months are not responding to counting in their native language, but are simply demonstrating a non-numerical preference to attend to objects paired with different ‘names’ (one to six). However, it is well established that infants reject multiple names for individual objects that are identical except for colour [15] so, on that account, both the correct and incorrect counting sequences would represent salient naming violations and no looking preference would be predicted.

Our data suggest that between the ages of 15 and 18 months, infants begin to learn the abstract principles governing correct counting via exposure to their cultural counting routine. We draw this conclusion based on three findings. First, experiment 1 revealed a developmental change whereby 15 month olds, as a group, did not prefer the correct counting sequences unlike the 18 month olds. This suggests that, prior to 18 months, infants do not have sufficient experience with counting to have extracted the one-to-one correspondence principle. This interpretation gains credibility when paired with the fact that for the combined sample of 15 and 18 month old Australian infants, there was a significant correlation between parent-reported weekly exposure to counting and infants’ attention to the correct counting sequences. There was no such correlation observed among the Japanese infants, probably owing to the small sample size or to the relatively low frequency of shared object-counting experiences reported by the Japanese parents. Finally, experiment 3 showed that 18 month olds’ preference for correct counting was only evident in their native language, e.g. when they recognized the count words. That infants failed to generalize their preference for principle-consistent counting sequences in another language supports Gelman & Gallistel’s [2] suggestion that the how-to-count principles are generative rules, abstracted efficiently from exposure to counting in the child’s native language. Although previous researchers have found that children as young as 2 years respect the one-to-one principle as soon as they begin to count [2,5,7], the current findings provide the first evidence that this principle is implicitly recognized at least six months before children produce any verbal counting behaviour. These results, therefore, demonstrate that at least one of the how-to-count principles is acquired well before counting is mastered or even begun. Infants begin learning about counting in the second year of life.

The current results provide partial support for Gelman & Gallistel’s [2] position that the how-to-count principles guide children’s learning to count but leave open crucial questions about the acquisition of the other how-to-count principles. Indeed, our finding that infants abstract one-to-one correspondence regularity from exposure to a cultural counting routine is also consistent with the view that understanding cardinality relies on mastery of the first few number terms [4,6,7]. The preferential looking procedure we have developed offers a promising new direction for examining this issue further by revealing what infants learn about their cultural counting routine prior to producing the behaviour.

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