

Abstract

The widely used MacArthur-Bates CDI includes cross-sectional studies of two populations - infants (8 to 16 months, N=659) and toddlers (16 to 30 months, N=1130). Using a new mathematical analysis, we determined that the onset age of actions and gestures predicts the much-later onset age of corresponding verbs. This finding supports the claim that early linguistic meaning is grounded in motor activity. The motivation for our new analytic method is the accurate determination of an onset age for each questionnaire item. The onset age is defined as the point at which 50% of the population has demonstrated the skill or capability. Our analysis uses a single fit function for all questionnaire items including action and linguistic items. The mathematical form of the fit function is theoretically justified using a normal distribution population model and is verified empirically. For each item, a good fit is obtained for all ages and it provides a measure of the statistical uncertainty associated with each onset age.

Summary

We use a new analysis of the MacArthur-Bates CDI cross-sectional Infant and Toddler datasets (~1000 individuals) to show that the age of learning a gesture or action (e.g., drinking) predicts the age at which the toddler produces the corresponding verb (e.g., "drink") a year later. Thus, an important, but little considered, factor contributing to verb learning is the toddler's own ability to take appropriate action.

Method

Our new method fits a Gaussian cumulative function to the entire developmental trajectory of each verb and gesture. Fitting the trajectory results in an accurate estimation of mean onset time. Then, each verb is associated with a gesture using two methods, and we perform a regression to predict verb onset time from gesture onset time.

Result

Infants use of gestures and action predict later onset of associated verbs.

Robust regression: $\text{verb-onset-month} = 0.45 \text{ gesture-onset-month} + 18.6$

$N=15, F=11.7, R^2=0.47, p<0.005$

Implications

- Neuro-physiological underpinnings of gesture and action production inform and constrain toddlers' verb production.
- Experimental support for embodied and grounded approaches to language development and use.

Child's Name _____ Sex _____
 Birthdate _____ Today's Date _____

The MacArthur Communicative Development Inventory: Words and Gestures

Please circle who filled out the form:
 Mother _____ Father _____
 Other (specify relation to child) _____

Part I Early Words

A. FIRST SIGNS OF UNDERSTANDING
 Before children begin to speak, they show signs of understanding language by responding to familiar words and phrases. Below are some common examples. Does your child do any of these?

	Yes	No
1. Respond when name is called (e.g., by turning and looking at you)	<input type="checkbox"/>	<input type="checkbox"/>
2. Respond to "no" (do not proceed what he/she is doing, at least for a moment)	<input type="checkbox"/>	<input type="checkbox"/>
3. Respond to "there's mommy/daddy" by looking around for them	<input type="checkbox"/>	<input type="checkbox"/>

Figure 1. Excerpt from the MacArthur-Bates Infant form.

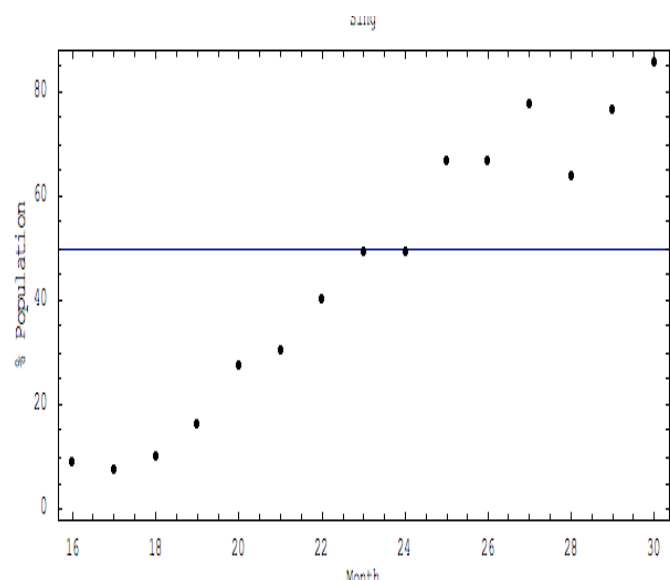


Figure 2. MacArthur-Bates Words and Sentences CDI : Fraction of toddler population by age that have demonstrated the production of the verb "sing."

Gesture Label	Verb
B01. playpeek	Play
B05. sing	Sing
B06. dance	Dance
C01. eatspoon	Eat
C02. drinkcup	Drink
C05. wipeownface	Wipe
C06. putonhat	Put
C10. blowhot	Blow
C14. pushtoycar	Push
C15. throwball	Throw
E01. sweep	Sweep
E06. pretendread	Read
E10. pretenddrive	Drive
E12. cleanwithcloth	Clean
E13. writepen	Write

Table 1. Gesture-Verb Map-1 created from CDI verb label of each gesture.

Gesture	Verb
A03. points	Look
B04. chasegames	Run
B05. sing	Sing
C01. eatspoon	Eat
C02. drinkcup	Drink
C05. wipeownface	Wash
C10. blowhot	Blow
C14. pushtoycar	Push
C15. throwball	Throw
E01. sweep	Clean
E06. pretendread	Read
E09. playmusinstr	Play
E10. pretenddrive	Drive

Table 2. Gesture-Verb Map-2 created from Illinois Daycare Workers Survey.

1. Background: The MacArthur-Bates CDI

The analysis presented here uses the two cross-sectional datasets of the MacArthur-Bates Communicative Development Inventory, originally published in 1996 (Dale & Fenson 1996):

- Words and Gestures ("Infant CDI") 8-16 months
- Words and Sentences ("Toddler CDI") 16-30 months

Development norms were established using two large surveys of infants and toddlers (N=659 and N=1130, respectively). Each month the parent completed either the Infant or the Toddler form (Fig. 1) and the submitted forms were subsequently combined into two large cross-sectional datasets. Each dataset includes the development trajectory for each survey item. For example, at 23 months of age, half the toddler population can produce the verb "sing" (Fig. 2).

2. Advantages of new MacArthur-Bates onset analysis

Original analysis by Dale & Fenson used linear and quadratic functions to fit the trajectories. However, the choice of linear or quadratic functions is arbitrary and does not fit the natural "S" shape of the trend data over the entire developmental period (16-30 months).

Further, a threshold onset analysis (a search for the earliest age at which 50% of population demonstrates the capability) incurs a large amount of systematic error and uncertainty because it is susceptible to the noise (uncertainty) of each data point near the 50% level (e.g. Consider Fig.2). Our approach is to fit a development "S" curve (cumulative distribution function) to each trend item. For each fitted verb (or action) the Gaussian width and Gaussian mean are free parameters, corresponding to the population variability and onset age respectively (Fig. 3).

3. From Gestures to the Spoken Verb

With the onset age and statistical certainty known for each verb and gesture measure by the MacArthur CDI, we can now examine the importance of early infant actions as a predictor for onset of verb production. Two semantic maps were created. The first map (table 1) used the original verb label defined for each action and gesture. With this approach 15 verbs have a measurable gesture onset age in the Infant CDI survey, sections ABC & E. A second, validation map was created from a survey of professional infant Illinois daycare-workers (N=22) (Table 2). Respondents selected a verb for each action or gesture and the gesture-verb pairing used dominant gesture-verb choices (i.e. >50% respondents chose the same verb for an action). When multiple gestures mapped to the same verb, the gesture with the earliest onset age was used.

4. Gesture and Actions to Verb regression analysis

Linear regression (See Fig. 4)

$$\text{verb-onset-month} = 0.45 \text{ gesture-onset-month} + 18.6$$

$$N=15, F=11.7, R^2 = 0.47, p < 0.005$$

Validation survey produced similar results (N=13, F=6.5, $R^2 = 0.37, p < 0.03$)

Infant gestures predict verb production one year later

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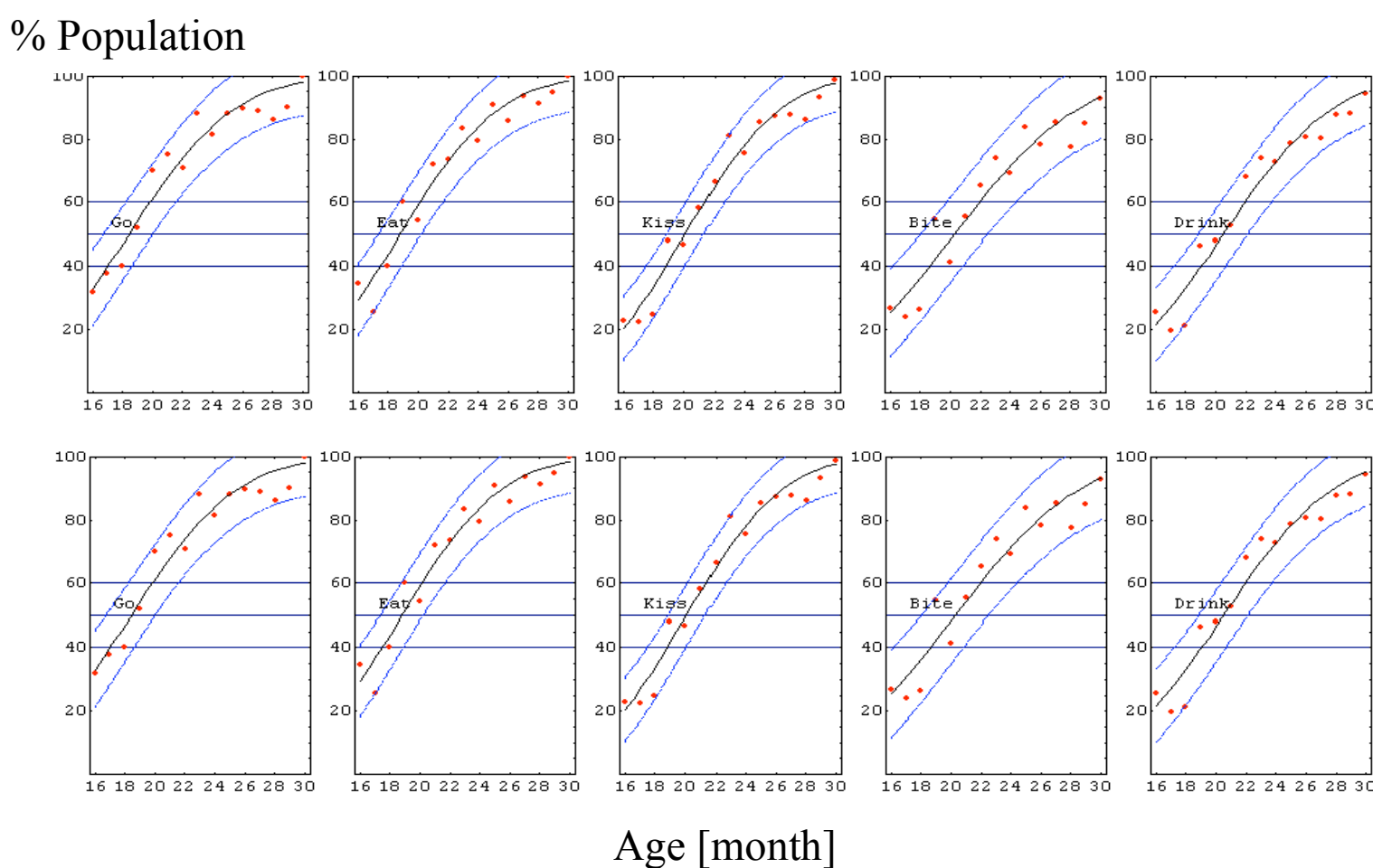


Figure 3. Fitting of a cumulative Gaussian function to the MacArthur-Bates population curves for ten verbs produced by toddlers. The fitted parameters (Gaussian width and mean) provide a measure of the age at which 50% of the population produces the gesture, action or verb.

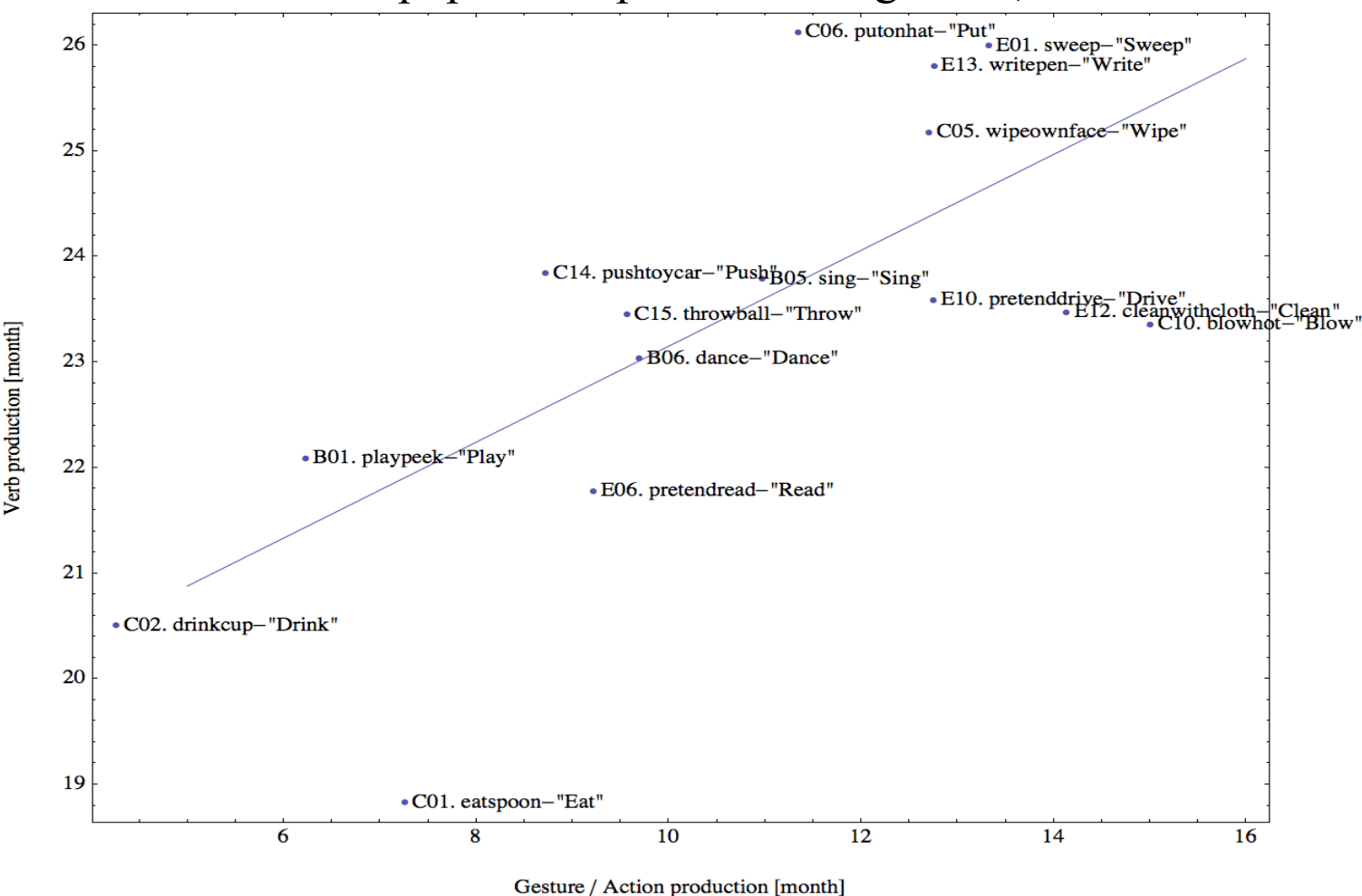


Figure 4. Onset of gestures and actions predict onset of verb production using G-V Map-1

5. Discussion

Our data are consistent with a) Huttenlocher, Smiley, and Charney (1983) who noted that children understood verbs for self-performed actions earlier than for actions performed by others, and b) Smith (2005) who demonstrated that children generalize labels to objects depending on the actions the children performed on those objects.

Apparently, an important component in being able to learn a verb is being able to produce the corresponding action or gesture. Why? Because it is the action that provides the meaning for the verb.

Why is there such a long delay between action production and verb production? We offer three speculative answers. First, onset of the gesture may not indicate that the gesture is firmly part of the toddler's action repertoire. Second, it is probably easier to learn from an adult model a visible arm action than an invisible articulatory action. Third, in some computational models of motor control (e.g., Wolpert & Kawato, 1998), the system first learns to predict the consequences of an action (e.g., comprehending what follows from hearing "drink") before the system efficiently learns to produce the action (e.g., saying the word "drink").

6. References

- Dale, P., & Fenson, L., (1996). Lexical development norms for young children. *Behavior Research Methods, Instruments & Computers* 28.1,125-127.
- Huttenlocher, J., Smiley, P., & Charney, R. (1983). Emergence of action categories in the child: Evidence from verb meanings. *Psychological Review*, 90, 72-93.
- Smith, L. B. (2005). Action alters shape categories. *Cognitive Science*, 29, 665-679.
- Wolpert, D.M., & Kawato, M. (1998). Multiple paired forward and inverse models for motor control. *Neural Networks*, 11, 1317-1329.

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