Learning to understand questions

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Abstract

Our aim in this paper is to characterise the learning process by means of which children get to understand questions. In contrast to the acquisition of *production* of questions, an area which has a long history, the emergence of question comprehension is largely uncharted territory. we limit our attention in this paper to *wh*–interrogatives, since generally there is overt evidence for their understanding before other types of questions such as polar questions. The general idea we follow is that the child learns to understand questions interactively, as there is a long period of "training" during which the carer asks questions and answers them himself. Since the answers can be understood by the child, given sufficient exposure the child deduces an association between the pre-answer utterance and a question. Nonetheless, the process as we describe it here assumes a number of very strong priors. In particular, we will be assuming for some stages of the process that the child is attuned to a very simple *erotetic logic*—a logic which given certain assumptions allows one to deduce questions. We provide evidence for our model based on classifying interactions between a child and her parents in the multimodal Providence corpus from CHILDES.

1 Introduction

Our aim in this paper is to characterise the learning process by means of which children get to understand questions. In contrast to the acquisition of *production* of questions, an area which, as we discuss in section 2, has a long history, the emergence of question comprehension is largely uncharted territory, to the best of our knowledge.

We equate the comprehension of a question with the ability to provide an answer that concerns the question (in the sense of aboutness answerhood (Ginzburg, 2010), hence no requirement that such an answer be true.).

The general idea we follow is that the child learns to understand questions interactively, as there is a long period of "training" during which the carer asks questions and, receiving no answer, answers them himself. Since the answers can be understood by the child, given sufficient exposure the child deduces an association between the pre-answer utterance and a question. Nonetheless, the process as we describe it here assumes a number of very strong priors. In particular, we will be assuming for some stages of the process that the child is attuned to a very simple *erotetic logic*—a logic which given certain assumptions allows one to deduce questions (Wiśniewski, 2013a). This means that one needs to distinguish between the task of question acquisition and the more purely cognitive task of the emergence of erotetic reasoning; of course a similar delimitation is required to distinguish the emergence of beliefs and the understanding of the contents of declarative utterances.

In terms of data, we limit our attention in this paper to *wh*–interrogatives, since generally there is overt evidence for their understanding before other types of questions such as polar questions—a potentially interesting puzzle for most theories of questions where the latter are somehow simpler entities. However, we do discuss which of the learning strategies we consider scales up to polar questions, and will extend the empirical coverage to polars in an extended version of this paper.

Beyond the intrinsic interest of the topic of the acquisition of questions, we think that this is a topic that can ultimately offer grounds for selecting among existing theories of questions on the grounds of learnability.

The structure of the paper is as follows: in section 2 we survey previous work on questions, on the acquisition of the production of questions, and on Bayesian learning. In section 3 we discuss the games by means of which we hypothesise questions get learnt. Section 4 provides the empirical evidence evaluating the plausibility of our approach.

2 Previous Work

2.1 Questions and Semantics

In considering how questions are acquired, we need to settle on a representation of the target entity, viz what a question is. Although there has been much work in formal semantics on the meaning of interrogatives (for surveys see e.g., (Groenendijk and Stokhof, 1997; Ginzburg, 2010; Wiśniewski, 2013b)), as Wiśniewski says 'No commonly accepted theory of questions has been elaborated so far.' The questions literature has not addressed the issue of how questions might be acquired, nor the cognitive plausibility of the semantic entity a given theory assumes as an interrogative denotation. On grounds of cognitive tractability, from among currently influential views, neither the partition theory, where a question is seen to be a partition of the set of possible worlds (for detailed motivation see (Groenendijk and Stokhof, 1997)), nor the inquisitive semantics view, where a question is seen to be a set of sets of worlds (see (Wiśniewski, 2013b) for detailed discussion) can be candidates (though one cannot rule out the possibility of cognitively tractable versions being formulated.). We will assume a view of questions as propositional functions, a view apparently initiated by (Ajdukiewicz, 1926), developed significantly in (Kubinski, 1960), and subsequently shared and further developed by a number of different approaches (Krifka, 2001). We adopt an implementation of this view within the framework of Type Theory with Records (Cooper, 2010). Specifically, it will be convenient to think of questions as records comprising two fields, a situation and a function (Ginzburg et al., 2014). The role of *wh*-words on this view is to specify the domains of these functions; in the case of polar questions there is no restriction, hence the function component of such a question is a constant function. (1) exemplifies this for a unary 'who' question and a polar question:

(1) a. $\textit{Who} = \begin{bmatrix} \mathrm{x}_1 : \textit{Ind} \\ \mathrm{c1} : \mathrm{person}(\mathrm{x}_1) \end{bmatrix}$; $\textit{Whether} = \textit{Rec}$;

b. 'Who runs' $\mapsto$ $\begin{bmatrix} \mathrm{sit} = r_1 \\ \mathrm{abstr} = \lambda r{:}\textit{Who}(\begin{bmatrix}\mathrm{c} : \mathrm{run}(r.x_1)\end{bmatrix}) \end{bmatrix}$;

c. 'Whether Bo runs' $\mapsto$ $\begin{bmatrix} \mathrm{sit} = r_1 \\ \mathrm{abstr} = \lambda r{:}\textit{Whether}(\begin{bmatrix}\mathrm{c} : \mathrm{run(b)}\end{bmatrix}) \end{bmatrix}$

Given this, the following relation between a situation and a function is the basis for defining key coherence answerhood notions such as resolvedness and aboutness (weak partial answerhood (Ginzburg, 2010)) and question dependence (cf. erotetic implication,(Wiśniewski, 2013b)):

(2) *s resolves* q, where q is $\lambda r : (T_1)T_2$, (in symbols $s?q$) iff **either**
(i) for some $a : T_1$ $s : q(a)$,
or
(ii) $a : T_1$ implies $s : \neg q(a)$

2.2 The emergence of wh-interrogative production

There appears to be a relatively robust order of acquisition of the production of wh-words in questions reported for a variety of languages, in which 'what' and 'where' (and their cross-linguistic equivalents) are acquired before other wh-words (e.g., 'why', 'how' and 'when') (Brown and Hanlon, 1970; Bloom et al., 1982). Bloom and collaborators proposed a complexity-based account. On this line, the first wh-questions to emerge are wh-identity questions—questions that ask for the identities of things or places. These are suggested to occur with what Bloom et al. term the 'relatively simple' 'what' and 'where', and should occur primarily with the copula. Later on, the *wh*-words, which now also include 'who', are envisaged to start occurring with a greater variety of main verbs (e.g. 'Where has he gone?', 'What are you doing?'). There have also been more recent alternative accounts of such phenomena in terms of input frequency (see (Theakston et al., 2001; Rowland et al., 2003), and references therein).

2.3 Bayesian learning and semantics

Recent years has seen the emergence of formal accounts of deep semantic learning rooted in a Bayesian approach to cognition.

(Piantadosi et al., 2012a; Piantadosi et al., 2012b) propose an approach which they apply to the learning of, respectively, numeral systems and quantifier expressions. The general strategy is to use the λ-calculus as a means for developing a hypothesis space (a *language of thought* for the learner, in the authors' words.). Restricting ourselves to the numeral case: a space of functions from sets to number words is defined (including a function representing knowledge that singleton sets can be counted by the word 'one', doubleton sets by 'two' and fails on any other type of set, a function that partitions all sets into either 'one' or 'many' etc). The crucial ingredient concerns how the learner chooses among these hypotheses: a probabilistic model is constructed built on the idea that the learner should attempt to trade-off two desiderata. On the one hand, the learner should prefer a lexicon having a short description in the language of thought. On the other hand, the learner should find a lexicon which can explain the patterns of usage seen in the world. Balancing these requirements is effected by using Bayes' rule.

Frank et al. (2009) attempt to synthesise two approaches to word learning, one based on recognition of speaker intention and one based on cross-situational learning. The model constructed consists of a set of variables representing the word-learning task and a set of probabilistic dependencies linking variables representing the lexicon of the language being learned, the referential intentions of the speaker, the words uttered by the speaker, and the learner's physical context at the time of the utterance. The physical context of an utterance is identified as the set of objects present during the utterance, the speaker's referential intention as the object or objects he or she intends to refer to, and the lexicon as a set of mappings between words and objects. Using an observed corpus of situations—utterances and their physical context—the model works backward using Bayesian inference to find the most likely lexicon.

We hypothesise these methods could be extended to learning the meanings of wh words. However, in both cases what we have is batch learning of sets of lexical items, which as the authors acknowledge makes no reference to the interaction between parent and child, so falls short of a theory of the process in which acquisition emerges.

3 Modelling

The narrative We consider three potential games of increasing complexity for learning questions. The first one will lead to success but can only enable the learning of a small class of questions. The second game is significantly more general, but still quite restricted. The third one is yet more general (though not fully sufficient for learning questions), but here success is far less clear. We hypothesise that this sequence can be used to explicate the order of comprehension of questions. To what extent this hypothesis is vindicated is discussed in section 4.

3.1 Salient Object Identification (SOI)

Priors understand 'that', shared gaze/deixis, predication

The game: training phase while sharing gaze at an object the parent asks a question that involves the child identifying the object or the object's location. The parent offers the child the opportunity to answer and when no response is forthcoming, the parent offers a name, attribute, or deictic gesture.[1]

Examples[2]

(3) a. [Mother turns page to reveal page with mirror on it.]: who's that? who's that ? huh ? can you see ? rabbit.

b. [Mother walks Big Bird up] who's that? who's that? is that Big_Bird ?

Rationale In the training phase the child is unsure how to respond: as far as a language like English that has *wh*–fronting, the initial hypothesis (given her existing lexicon of NP meanings) is that 'what' or 'who' is referential; this conflicts with the normal structure of copular sentences (*Bo is that, *The ball is this). Still, in the absence of an alternative, some initial high probability has to be assigned to the hypothesis that these words are referential. Since the range of questions asked is small, it is feasible to be making and retaining hypotheses about the meaning of this (type of) unclear utterance. Once the parent provides the relevant answer, the child understands the answer

[1] We are assuming that turn taking is being acquired independently, as a tool used in a variety of move types, indeed not just for linguistic purposes.

[2] All the examples in this section are taken from the Rollins corpus, (Rollins, 2003).

since the word is chosen to be known to the child and it predicates of the entity in visual focus.

It is not clear though that there is anything in this interaction to argue *against* the hypothesis that the 'wh' words refer to the entities picked out,[3] Nonetheless, given sufficient exposure to this game, the child gets habituated to associating with the utterance of the interrogative utterance the predication of a property of the salient entity in the situation and this process does involve the child considering various possible properties for classifying that entity. In other words, a data structure individuated by a situation and a function, as in (1b). So there is a holistic content associated with the interrogative utterance, not one built up compositionally.

weaknesses This game underdetermines answerhood since neither negative nor quantified answers will be encountered. Furthermore, it will not scale up to learning other types of questions, most obviously polar questions.[4]

3.2 Erotetically plausible questioning

Priors understand 'that', shared gaze/deixis, predication, an erotetic inference capability (Wiśniewski, 2013a)—awareness that certain situations raise questions: when shown an object, the question will be: who/what is that?; when an object disappears, the question will be: where is SO?; seeing animal, what noise does it make? seeing an object: what things can it do? etc. We call questions deduced in this way in context *erotetically plausible questions* (EPQ). The erotetic capability assumed is a parameter of the game—different games will ensue with the assumption of different erotetic capabilities.[5]

[3]There is Eve Clark's contrast principle (Clark, 2002) which is potentially of some help, given the need to distinguish 'what' or 'who' from 'that'. But given they do differ from 'that' via their associated restrictions, it is not obvious that would be sufficient.

[4]There are clearly polar question oriented games, such as those where a child gets to respond by shaking their head as a negative response. What is important to ascertain is how general the notion of negation used there is, to what extent this is distinct from expressing a negative volition. We hope to investigate this point in subsequent work.

[5]An anonymous reviewer for SemDial cautions us from identifying too closely the notion of erotetic inference capability with that associated with e.g., Wiśniewski's IEL. This is of course a reasonable point, though in pointing towards formalisms like IEL our intention is to highlight the apparent use of reasoning that employs questions, not solely propositions. IEL is in any case a rather general framework, consistent with many distinct conceptions of semantics and reasoning.

The game: training phase in a situation s the parent asks a question that is EPQ in s. The parent offers the child the opportunity to answer and when no response is forthcoming, the parent offers an answer.

Examples

(4) a. [Mother pulling hair from rattle]: where is all this hair coming from?

b. [Mother removes big bird] Where did Big Bird go? [pulls big bird up into line of sight] peek a boo.

Rationale The EPQ game generalises SOI by allowing a wider range of questions, emphasising the likelihood of the question in context; it can, in principle, scale up to polar questions (e.g., pressing a balloon from both sides raises the issue of whether it will burst.) and a wider range of answers. Understanding the answer is less deterministic than with SOI since a given context could be compatible with a number of questions arising. But, once again, a small number of possible questions and sufficient training potentially habituate the child to associate situations which trigger erotetic inferences with questions in a holistic way.

weaknesses There is the potential for mismatch between the child's internal erotetic capabilities and those associated with the natural language used. The range of potential questions that can be learnt in this way is still severely restricted.

3.3 Situational Description Games

Priors Similar to EPQ games.

The game: training phase In a situation s the parent asks questions about properties of objects in the observed situation, described using words the child knows. The parent offers the child the opportunity to answer and when no response is forthcoming, the parent offers an answer.

Examples

(5) a. [Mother looks at book]: what kind of colors do we have here ? [puts book on tray] look there's purple. that's Mot [= mommy's] favorite color. and pink. and blue.

b. [Child holding car] what's on this car ? [grabs other side of car Chi has in hand and turns it over .] this car has a butterfly sticker on it.

Rationale This game can be extended to cover an unrestricted range of questions (though of course by no means the full range of NL questions.).

weaknesses There is no guarantee that the child will understand the answer, hence there is no guarantee that learning of a given interrogative meaning will succeed. But assuming the child has been well trained with EPQ, the child will habituate to associate interrogatives with a wider range of questions than EPQ.

3.4 Formal characterisation of the games

Each of these games can be characterised formally as a *genre* in the sense of (Larsson, 2002; Ginzburg, 2010)—an interactional sequence with restricted subject matter. We demonstrate how to do so in the extended version of this paper.

4 Data

We randomly sampled and selected 20 wh-questions of each file (31–48% of all wh-questions present in the files[6]) from early files of Naima of Providence corpus (Demuth et al., 2006). These questions were annotated for their form, child's response, mother's follow-up, evaluation of child's answer, and the semantic model that describes them best (SOI, EPQ, SDG, as discussed previously).

4.1 Caregiver's questions

Naima's parents asked 'what' and 'where' questions most frequently (see Table 1). As shown in Table 2, the SOI question interactions almost solely occur with copular structures, whereas the other more complex games appear with a wider range of constructions. We did not find any evidence that caregivers present children with the games we discuss above sequentially (i.e. frequency of the games did not change in favor of more complex ones over time.). One could argue however, that the relatively simple, almost fixed, structure[7] of questions in SOI makes those questions more tractable and bootstraps the learning process.

[6]Wh-questions comprised 24.4–30.3% of all questions (including polar questions, choice questions, etc.).

[7]We take the word type following the wh-word to be a reasonable proxy for measuring structural complexity.

	which	who	who else	where	what	what else
SOI	1	8	0	4	11	0
EPQ	0	1	0	3	10	1
SDQ	0	1	1	23	23	4
OTH	0	0	0	1	8	0
total	1	10	1	**31**	**52**	5

From files 1, 3, 5, 7, and 9 of Naima

Table 1: Frequency of wh-words with the semantic class of the question

	SOI	EPQ	SDG	other
—	0.04	0.07	0.08	0.11
AUX	0.04	0.07	0.21	0
MOD	0	0.07	0	0.11
COP	**0.92**	0.40	0.56	0.33
DO	0	0.27	0.13	0.44
V	0	0.13	0.02	0

From files 1, 3, 5, 7, and 9 of Naima

Table 2: Percentages of forms following wh-word in parental questions and their semantic class

4.2 Children's answers

The annotator judged the correctness of child's response with respect to the question and the situation and tagged the instances as Correct (C), Type Correct (TC), Incorrect (IC), and Not Attempted (NoA).

We argued above that SOI and EPQ questions are easier for child to answer compared to SDG. Table 3 shows that SOI and EPQ questions get answered more often and might therefore be easier to learn.

Naima was more likely to attempt answering (irrespective of the correctness of the answer) SOI and EPQ questions compared to SDG and these attempts also increased by age ($Pr(>|t|)s < .05$). We observed the same patterns for the correctness of the answers (i.e. SOI and EPQ questions were answered more correctly (on the scale of NoA <

Sem	answered C/TC (%)	total (#)
SOI	58	24
EPQ	60	15
SDG	38	52
Other	12	8

From files 1, 3, 5, 7, and 9 of Naima

Table 3: Percentage of questions answered by child

	Sem (% answered C/TC)				
Age	SOI	EPQ	SDG	Other	total
11.28	60	33	14	0	30
12.28	67	67	45	–	55
13.25	33	–	33	0	30
14.23	100	100	40	0	45
15.12	67	100	57	33	60

From files 1, 3, 5, 7, and 9 of Naima
Ages in month.days

Table 4: Percent questions answered by child over age

	Estimate	Std. Error	t value	$Pr(>\|t\|)$
(Intercept)	-1.752	0.580	-3.020	0.003 **
SemEPQ	1.409	0.667	2.113	0.037 *
SemSOI	1.595	0.584	2.731	0.007 **
SemOTH	-2.040	1.123	-1.817	0.072 .
Age	0.256	0.091	2.803	0.006 **

Signif. codes: 0.0001 *** 0.001 ** 0.01 * 0.05 . 0.1
Formula : CEval ∼ Sem + Age Intercept terms (reference levels): No Answer, SDG, and Youngest age.

Table 5: Best fitting model of evaluation of child's answer

IC < TC < C) than SDG questions and age of the child showed a positive main effect on this correctness. See Table 5).

We also annotated the type of answer Naima provided to her mother's question as "ShortAns" when she responded with a single word utterance that was relevant to the question, and as "ActAsAns" when she responded to the question with a relevant action. We coded utterances that did not pertain to the question with "IrRel" and no attempt to answer as "NoA". Our Fisher's exact test revealed that a child's answer to a question significantly differed by its semantic class (p-value = 0.041). Using correspondence analysis, Figure 1 illustrates the trends in this correlation: Child's ShortAns cooccurs with SOI, and to a lesser degree with EPQ. This was expected from analyses of answer attempts and answer correctness discussed earlier.

4.3 Mother's follow-up

Table 6 summarises our annotation schema for mother's follow-up utterances along with percentages of their occurrence in the data sampled from Providence (Demuth et al., 2006). The child's answers to the questions correlated significantly with

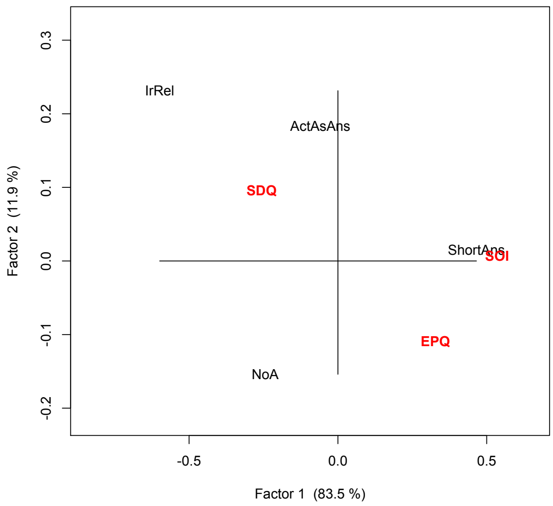

Figure 1: Correspondence analysis graph for child's answer and semantic class of the question

the mother's follow-up utterance (p-value = 5.24e-06). As indicated in Figure 2, the mother's IrRel follow-up is positively correlated with the child's IrRel; this is most likely due to a shift of topic or attention in the conversation. When the child gives no answer (NoA), the mother proceeds with reformulations (Rfl) or repetitions (Rpt) of the same question, or asks a new related question (RNQ). The child's answers (ShortAns and ActAsAns) on the other hand get meaningful feedback from the mother (ShortAns, SentAns:Simple, YES).

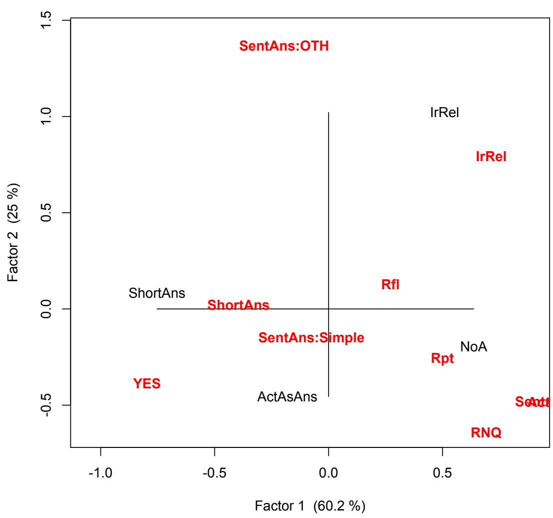

Figure 2: Correspondence analysis graph for child's answer and mother's follow-up

Mother's follow-up	%		Example
ShortAns	13	Short Answer	MOT: what is it? MOT: lego.
SentAns:Simple	18	Simple Sentential Answer	MOT: what's that? CHI: yyy dog. MOT: that's a little dog.
SentAns:PQA	4	Polar Question Answer	MOT: who's that? MOT: is that the doctor?
SentAns:OTH	2	Other sentential answer	MOT: what's that? CHI: shirt[?] shirt[?] MOT: it looks like pants to me but that's close.
ActAsAns	1	Action as answer	
Rfl	15	Reformulation	MOT: what's that? CHI: yyy. MOT: you know what that is?
Rpt	14	Repetition	MOT: where's dolly Naima? MOT: where's dolly?
RNQ	4	Related New Question	MOT: where's pipo? MOT: what's he doing?
IrRel	10	Irrelevant utterance	
RCA	10	Repeat Child's Answer	MOT: where'd [: where did] it go? CHI: down. MOT: down.
YES	9	Acknowledge Child's Answer	MOT: who else do we see in that picture? CHI: pony. MOT: yeah.

Percentages and examples from Naima, files 1, 3, 5, 7, and 9.

Table 6: Mother's follow-up utterances

4.4 Earlier input

We also looked at 18 files from the Rollins corpus (Rollins, 2003) to investigate to what extent caregivers provided answers to their own questions during the stage where children didn't produce any answers at all.[8] Table 7 indicates that even in the earlier stages caregivers answer about half of their own questions.

We did not find any significant effect of age on question words or mother's follow-up. Individual differences however, were significant for question word (X-squared $= 333.39$, $df = 63$, p-value $< 2.2e - 16$). The numbers of 'what' and 'where' questions were significantly different for different mothers ($Pr(> |z|) < 0.01$)[9].

The complexity of the question forms, as measured by the second word[10], changed significantly with children's age with individual differences accounted for as random effects[11].

5 Conclusions and Future Work

In this paper we have offered a sketch of a theory of the emergence of question comprehension by children, within a type theoretic view of questions as situationally relativized propositional functions. We have outlined how this might happen with reference to certain restricted interaction sequences between parent and child, tying this to ease of classification of situations and erotetic inference capability that children develop. The data we present from the interactions of one child in the Providence corpus with her parents offers encouraging indications that the notions of question complexity we postulate are on the right track.

An important component that remains to be spelled out is the probabilistic reasoning underlying the various habituation states we have conjectured.

[8]Out of 422 questions, only 7 were answered to by children; only 2 of those answers were verbal.

[9]Generalised linear model with mother as dependent variable and question word as predictor.

[10]Words occurring right after question word were of the types: AUX, COP, MOD, DO, and V.

[11]Generalised linear mixed model Formula: $age \sim SecondWord + (1|name)$

Mother's follow-up	Children (% Mother's follow-up) cb	di	ds	hc	im	jw	me	nb	sx	mean
ActAsAns	5.6	5.9	2.5	14.0	1.6	6.9	2.0	14.0	8.1	6.73
IrRel	11.0	5.9	25.0	14.0	11.0	17.0	13.0	28.0	16.0	15.7
Rfl	11.0	0.0	2.5	14.0	20.0	24.0	25.0	10.0	19.0	13.9
Rpt	11.0	24.0	28.0	32.0	16.0	14.0	20.0	12.0	14.0	19.0
SentAns:OTH	5.6	8.8	2.5	4.5	3.3	10.0	5.0	3.8	8.1	5.73
SentAns:PQA	11.0	32.0	0.0	9.1	25.0	6.9	15.0	5.0	11.0	12.8
SentAns:Simple	22.0	12.0	30.0	0.0	11.0	10.0	12.0	7.5	11.0	12.8
ShortAns	22.0	12.0	10.0	14.0	11.0	10.0	8.9	20.0	14.0	13.5
Answered	66.2	70.7	45.0	41.6	51.9	43.8	42.9	50.3	52.2	51.62
Answered verbally	60.6	64.8	42.5	27.6	50.3	36.9	40.9	36.3	44.1	44.9

Ages 9 and 12 months of nine children from Rollins corpus.

Table 7: Distribution of Mother's follow-up to her own questions

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