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Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 26(26)

ISSN

1069-7977

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Publication Date

2004

Peer reviewed

Expressions Related to Knowledge and Belief in Children's Speech

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Abstract

Children develop certain abilities related to Theory of Mind reasoning, particularly concerning the False-belief Task, between the ages of 3 and 5. This paper investigates whether there is a corresponding change in the frequency of linguistic expressions related to knowledge and belief produced by children around these ages. Automated corpus analysis techniques are used to tag each expression related to knowledge and belief in a large corpus of transcripts of speech from normally developing English-learning children. Results indicate that the frequency of expressions related to knowledge and belief increases steadily from the beginning of children's language production. Tracking of individual concepts related to knowledge and belief indicates that there are no clear qualitative changes in the set of concepts that are expressed by children of different ages. The implications for the relationship between language and the development of Theory of Mind reasoning abilities in children are discussed.

A Developing Theory of Mind

Among the most interesting of human cognitive abilities are those concerning how we understand and reason about the minds of others. The term *Theory of Mind* is used pervasively throughout the cognitive sciences to refer to the set of abilities that enable people to reflect introspectively on their own reasoning, to empathize with other people by imagining what it would be like to be in their position, and to generate reasonable expectations and inferences about mental states and processes.

Within the research area of developmental psychology, Theory of Mind has been studied as a set of cognitive abilities that progressively emerge in children. A standard experimental instrument for studying children's Theory of Mind abilities is the false-belief task. In a standard version of this task (Wimmer & Perner, 1983), the child is introduced to two characters, Maxi and his mother. Maxi places an object of interest into a cupboard, and then leaves the scene. While he is away, his mother removes the object from the cupboard and places it in a drawer. The child is then asked to predict where Maxi will look for the object when he returns to the scene. Success on this task has been criticized as neither entirely dependent on Theory of Mind abilities nor broadly representative of them (Bloom & German, 2000), however its utility has been in reliably demonstrating a developmental shift. Wellman et al. (2001) analyzed 178 separate studies that employed a version of this task, finding that 3-year-olds will consistently fail this task on the majority of trials by indicating that Maxi will look for the object in the location to which his mother has moved it. 4-year-olds will succeed on half the trials, while

5-year-olds will succeed on the majority of trials. Call & Tomasello (1999) demonstrate that these results are consistent across verbal and non-verbal versions of this task.

Children's developing performance on the false-belief task is particularly interesting when couched within the larger debate concerning *maturational* and *conceptual change* in cognitive development. Like every other cognitive ability that emerges in childhood, performance on Theory of Mind tasks is likely due to a complex combination of maturing innate abilities and knowledge learned through experience. Still, understanding the relative importance of these two factors may have some utility in evaluating two types of cognitive process models that have been proposed to account for human Theory of Mind abilities.

First, *Theory Theory* hypothesizes that Theory of Mind abilities are computed by prediction and explanation mechanisms by employing representation-level knowledge about mental attitudes (Gopnik & Meltzoff, 1997; Nichols & Stich, 2002). Second, *Simulation Theory* argues that Theory of Mind abilities are computed by imagining that you are in the place of the other person, then inferring their mental states by monitoring the processing that is done by your own cognitive abilities (Goldman, 2000). With respect to the development of Theory of Mind abilities in children, each of these theories would emphasize different things as most important. Theory Theorists would argue that the acquisition of mental models of commonsense psychology would play the most important role, a view consistent with a conceptual change model of development (e.g. Bartsch & Wellman, 1995). In contrast, Simulation Theorists would look instead for a maturational change that enabled children to take the perspective of other people or in the monitoring of one's own mental state, a view consistent with a modularity model of development (e.g. Scholl & Leslie, 2001).

One approach to investigating this issue is to look for evidence of the acquisition of mental models of commonsense psychology in the language that children use in everyday conversation. The contemporary view of natural language understanding and generation presupposes that the meaning of verbal expressions are representational in nature, and that these underlying representations are the same ones that would be manipulated for the purposes of inference (e.g. explanation and prediction). By tracking the production of children's speech that references commonsense psychology concepts, we can look for some correlation between linguistic competency with commonsense psychology concepts and emerging Theory of Mind abilities.

In this paper, we explore the progressive use of expressions that reference commonsense psychology concepts in children's language. The approach that we take in this investigation is to employ automated corpus analysis techniques developed within the computational linguistics research community, where the aim is to construct computer programs to reliably recognize every possible way of expressing a concept within a given language. In using automated corpus analysis techniques, we were able to quickly analyze each of the datasets within the CHILDES linguistic corpus (MacWhinney, 2000) that contained transcriptions of normally developing, monolingual English-learning children.

The specific interest that we had in conducting this research concerned the acquisition of a linguistic competency for concepts related to knowledge and beliefs, as they are the most relevant to the false-belief task described earlier. By examining the correspondences between these linguistic competencies and the ages in which children acquire cognitive competencies in Theory of Mind tasks, our aim is to provide an additional point of evidence that can be used in arguing for or against the competing models of the cognitive processes that underlie these abilities.

The Theory of Mind in Language

The Theory of Mind in Language project at the University of Southern California is an effort aimed at developing a large-scale lexical-semantic resource for the automated annotation of commonsense psychological concepts expressed in English text. This resource is being authored as a set of local grammars, encoded as finite-state transducers that can be applied to large text corpora for concept-level tagging and markup. Associated with each unique concept tag in the resource is a local grammar that has been hand-authored with the aim of recognizing every possible way that the concept could be expressed in the English language.

The application of these local grammars to text documents produces an annotated text, where each English expression that is recognized as referencing a commonsense psychological concept is tagged. The following paragraph (from William Makepeace Thackeray's 1848 novel, *Vanity Fair*) provides an example of the output of the application of this lexical-semantic resource.

Perhaps [*partially-justified-proposition*] she had mentioned *the fact* [*proposition*] already to Rebecca, but that young lady did *not appear to* [*partially-justified-proposition*] have *remembered it* [*memory-retrieval*]; indeed, vowed and protested that she *expected* [*add-expectation*] to see a number of Amelia's nephews and nieces. She was quite *disappointed* [*disappointment-emotion*] that Mr. Sedley was not married; she was *sure* [*justified-proposition*] Amelia had said he was, and she *doted so on* [*liking-emotion*] little children.

The tag set that is being used in this lexical-semantic resource was developed first through the large-scale analysis of strategies, defined as the abstract structural commonalities that exist between analogous planning cases (Gordon, 2002). 635 concepts resulting from this analysis (grouped into 30 representational areas) were related to a Theory of Mind, which constitutes the broadest cognitive science specification of a representational Theory of Mind to date. Gordon & Hobbs (2003) describe how this tag set is modified through the process of examining the breadth of English language expressions that are related to a given representational area, among the 30 in the complete set. Gordon et al. (2003) describes the process of constructing local grammars for each of the concepts in the revised tag set, encoded as finite-state transducers, and describes an evaluation to determine the effectiveness of this approach at automatically recognizing every English expression that refers to the concept tag in written text.

One of the 30 representational areas described in this previous work, Managing Knowledge, specifically deals

Managing knowledge (37 concepts)

He's got a logical mind (*managing-knowledge-ability*). She's very gullible (*bias-toward-belief*). He's skeptical by nature (*bias-toward-disbelief*). It is the truth (*true*). That is completely false (*false*). We need to know whether it is true or false (*truth-value*). His claim was bizarre (*proposition*). I believe what you are saying (*belief*). I didn't know about that (unknown). I used to think like you do (*revealed-incorrect-belief*). The assumption was widespread (*assumption*). There is no reason to think that (*unjustified-proposition*). There is some evidence you are right (*partially-justified-proposition*). The fact is well established (*justified-proposition*). As a rule, students are generally bright (*inference*). The conclusion could not be otherwise (*consequence*). What was the reason for your suspicion (*justification*)? That isn't a good reason (*poor-justification*). Your argument is circular (*circular-justification*). One of these things must be false (*contradiction*). His wisdom is vast (*knowledge*). He knew all about history (*knowledge-domain*). I know something about plumbing (*partial-knowledge-domain*). He's got a lot of real-world experience (*world-knowledge*). He understands the theory behind it (*world-model-knowledge*). That is just common sense (*shared-knowledge*). I'm willing to believe that (*add-belief*). I stopped believing it after a while (*remove-belief*). I assumed you were coming (*add-assumption*). You can't make that assumption here (*remove-assumption*). Let's see what follows from that (*check-inferences*). Disregard the consequences of the assumption (*ignore-inference*). I tried not to think about it (*suppress-inferences*). I concluded that one of them must be wrong (*realize-contradiction*). I realized he must have been there (*realize*). I can't think straight (*knowledge-management-failure*). It just confirms what I knew all along (*reaffirm-belief*).

Figure 1. Example expressions for 37 concepts related to Managing Knowledge.

with the concepts surrounding knowledge and belief, including assumptions, contradictions, justifications, logical consequences, truth, falsehood, and the mental processes associated with these commonsense psychological entities. Gordon et al. (2003) describe 37 concept tags associated with this area, which is presented here in Figure 1. The evaluation described in this previous work indicated that the lexical-semantic resources associated with this specific subset of the tag set was effective at identifying 83.92% of the expressions associated with these tags in English written text (recall score), and that 92.15% of the tagged expressions would be judged as appropriate by a human rater (precision score).

References in the CHILDES Corpus

As a corpus of analysis, we utilized the CHILDES database of children’s speech (MacWhinney, 2000), a collection of transcripts from a wide variety of psycholinguistic studies conducted largely in the 1980s. Specifically, we analyzed the transcripts from the 42 research studies that contributed data of normally developing monolingual English-learning children.

To facilitate the analysis of this dataset according to the age of the children, individual files were generated containing only the transcripts of speech produced by a single child for each of the transcript files (a total of 3001 individual files). The total number of words in each file was calculated and the age of the child (in months) was recorded. There were 3,347,340 words transcribed in these files from children ranging in age from 11 to 87 months.

Figure 2 presents a histogram of the number of words in the files associated with each age of the children. The notable spike that appears in this figure is due to a large dataset that exists within the CHILDES database contributed from a study by Hall et al. (1984). The groups of children are collectively identified only as being between the ages of 54 and 60 months without differentiation, so all of this dataset was used for evidence at the low end of this range. More significantly, Figure 2 reveals that comparatively little data exists within the CHILDES corpus of normally developing monolingual English-learning children after the

age of 5 years (60 months). Although the available data should allow for the observation of some interesting trends throughout the age range of the corpus, some caution is necessary when drawing strong conclusions about children older than 60 months.

In order to enable comparisons between children and adults, each of the analyses were also conducted on the CALLHOME American English Speech data collected and transcribed by the Linguistic Data Consortium (1997). The CALLHOME database consists of transcripts of 120 unscripted telephone conversations (302,083 words) between native speakers of English, where the callers average 38.875 years in age ($\sigma=16.14$).

Given these text corpora, two sets of analysis were conducted. Both of these analyses involved the use of tag frequency as data points. To compute tag frequency, the local grammars described in the previous section were applied to a corpus in order to find every expression within the corpus that should be tagged with the concept associated with each local grammar. The number of tagged expressions was then divided by the number of words that were searched to compute each frequency data point. In the first analysis, the frequency of all expressions of the 37 concepts related to knowledge and belief were tabulated for each of the datasets. In the second analysis, the frequencies of expressions related to each individual concept (of the 37 total) were tabulated.

No attempt was made to filter the results of the application of the local grammars to improve precision, and no evaluation was conducted to estimate the recall rate on these corpora. However, after reviewing the resulting tags we believe that the precision and recall scores obtained on these corpora are only marginally less than was achieved in the evaluation of written text tagging conducted by Gordon et al. (2003) using the same set of local grammars.

Frequency of all expressions related to knowledge

The first analysis that we conducted was to apply all of the local grammars for the 37 concepts related to knowledge and belief to each of the data files corresponding to children of different ages. In all, there were 18,283 tags produced

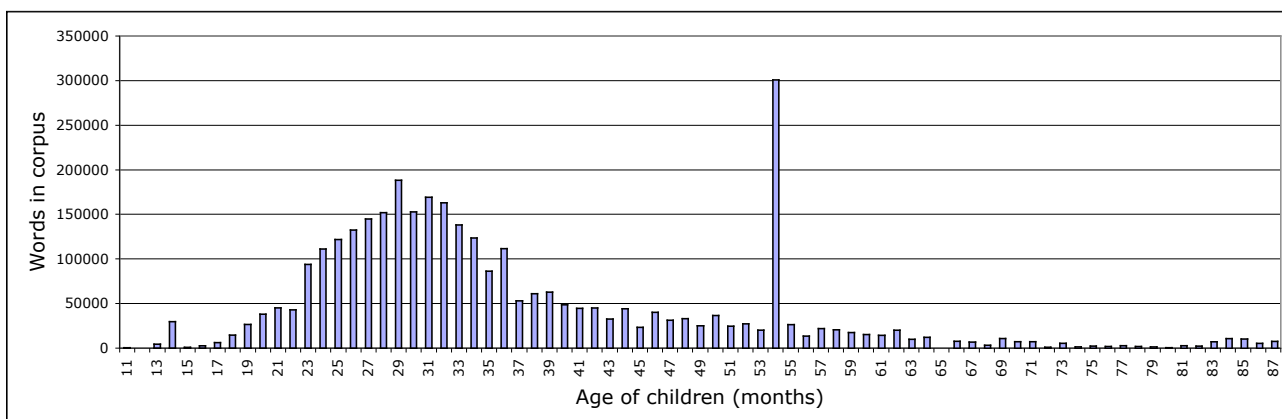


Figure 2. Number of words in corpus by age of children in months

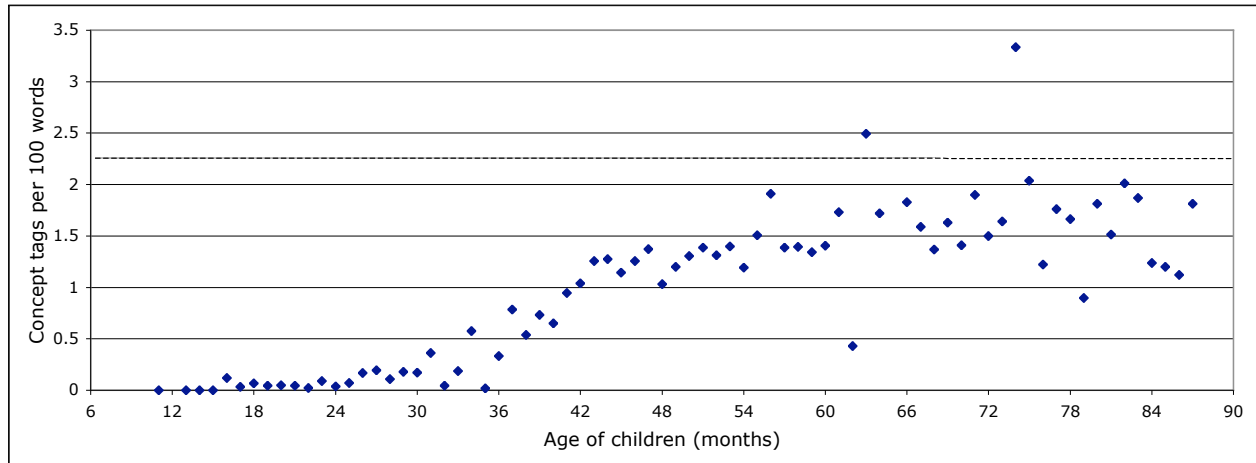


Figure 3. Frequency of all expressions related to knowledge and belief by age of children

through the application of these local grammars, with only 19 of the 37 tags appearing in the data. Nearly half of these tags were for the concept of a justified proposition (9113 tags), while the remaining half was dominated by tags to the concepts of belief (3150 tags), contradictions (3485 tags), and partially-justified propositions (1483 tags).

Applying the full set of local grammars to the CALLHOME data set produced 6775 tags, yielding a frequency of 2.24 reference per 100 words of speech. 21 of the 37 tags were assigned to this data, with the highest frequencies going to the concepts of justified proposition (3172 tags), contradiction (1551 tags), belief (1000 tags), and partially-justified proposition (493 tags).

Figure 3 presents a graph of the frequency per 100 words of speech for all expressions related to the concepts of knowledge and belief based on the age of the children (in months) of the analyzed data. As a point of comparison, the frequency for the CALLHOME data (2.24) is also indicated on the graph as a dashed horizontal line. The data on the

graph can be described by the linear function $y=0.0281x - 0.3914$, where the correlation statistic (r^2) is 0.7021.

The results indicate that expressions related to knowledge and belief do not appear at the beginning of children's speech production, but increase in frequency in a strongly linear manner from 30 months (2.5 years) until 48 months (4 years), when the frequencies of these expressions are roughly half of what is observed in adult conversational speech.

Frequency of expressions of individual concepts

In the second analysis, we individually applied each of the 19 local grammars that produced at least one tag in the corpus to each of the transcript data for children of different ages. The primary purpose of this analysis was to track the relative increase in frequency for each concept over the developmental period where a change in Theory of Mind abilities is evident (between 36 and 60 months of age).

	Total tags	24 mo.	30 mo.	36 mo.	42 mo.	48 mo.	54 mo.	60 mo.	CallHome
add-assumption	499	0.27	0.65	1.34	3.31	0.91	4.22	2.59	5.16
assumption	22	0	0	0	0	0	0.17	0	0.07
belief	3150	0.72	3.21	3.67	17.67	18.71	12.39	24.63	33.1
bias-toward-disbelief	26	0	0	0	0	0	0.17	0.65	1.22
check-inferences	4	0	0	0	0	0	0	0.65	0.23
consequence	1	0	0	0	0	0	0	0	0.26
contradiction	3485	0	0	0	22.09	29.27	30.43	27.22	51.34
false	69	0	0	0	1.1	0.6	0.37	0.65	0.26
ignore-inference	1	0	0	0	0	0	0.03	0	0
justified-proposition	9113	2.07	13.02	28.35	51.46	45.87	61.42	73.23	105
knowledge	5	0.09	0	0	0	0	0	0	0.53
managing-knowledge	26	0	0	0	0	0	0.33	0	0.36
partial-domain-knowledge	23	0	0	0	0.22	0	0.2	0	0.6
partially-justified-proposition	1483	0.27	0	0	6.85	6.04	7.77	8.43	16.32
reaffirm-belief	19	0	0.26	0	0	0	0.13	0	0.36
realize	229	0.18	0.13	0.09	0.22	1.81	1.3	2.59	5.63
true	67	0	0.07	0	0	0	0.47	0	2.02
unjustified-proposition	51	0	0	0	1.1	0	0.07	0	0.93
world-model-knowledge	10	0	0	0	0	0	0	0	0.73

Figure 4. Frequency of expressions of individual concepts related to knowledge and belief (tags per 10,000 words)

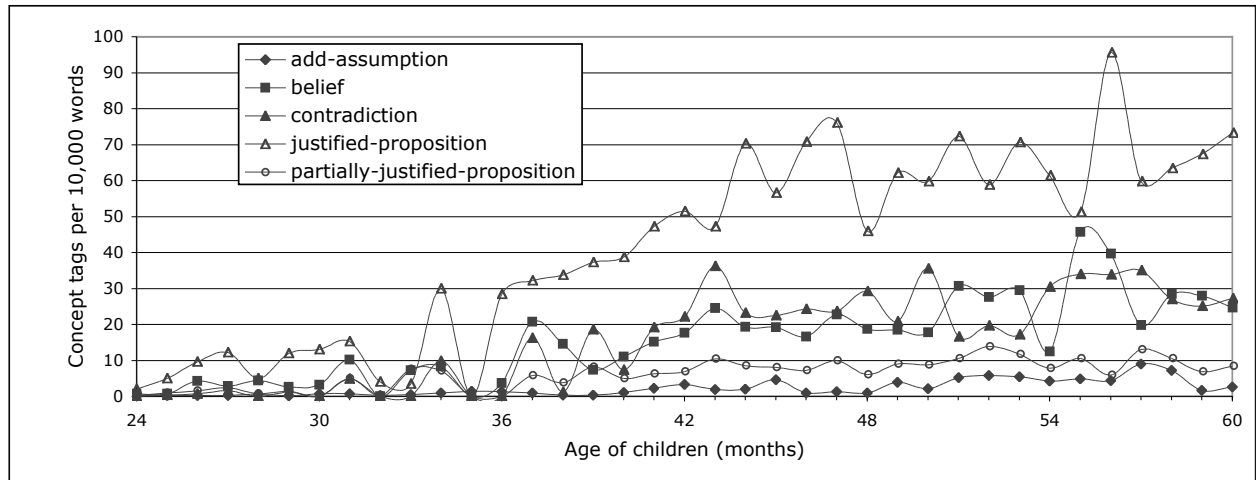


Figure 5. Frequency of expressions of the 5 most frequent individual concepts by age of children

Figure 4 presents a chart of the results of this analysis. Each concept is listed with the total number of tags assigned in the corpus and frequencies of occurrence within the data sets for 24, 30, 36, 42, 48, 54, and 60 month-old children, along with the CALLHOME frequency for the concept. Figure 5 further describes the results of this analysis by charting the growth in frequency of expressions related to the 5 most frequent concepts tagged in the corpus (add-assumption, belief, contradiction, justified-proposition, and partially-justified-proposition) between the ages of 24 and 60 months.

The results indicate that the increases in overall frequency of expressions related to knowledge and belief can be attributed to a steady increase in expressions related to a handful of concepts, particularly the concepts of belief, contradiction, and justified-propositions. This steady increase begins at 24 months and continuing past 48 months, when the frequencies of these expressions are roughly half of what is observed in adult conversational speech evidenced by the CALLHOME corpus. There is no evidence of any qualitative change in the sorts of concepts related to knowledge and belief that are expressed by children of different ages.

Discussion

The overall purpose of this study was to determine the relationship between a linguistic competency in the production of expressions related to knowledge and belief and children's developing Theory of Mind abilities, particularly during the age range where children acquire competency on the false-belief task (between 3 and 5 years in age). In this section, we will consider the results of our analysis with respect to this purpose.

First, there is no evidence to suggest a qualitative change in the *frequencies* that children express concepts related to knowledge and belief between the ages of 3 and 5. Looking first only at the frequency of all expressions related to knowledge and belief we see that children between the ages of 3 and 5 are continuing a steady increase in frequency that

started at the beginning of their speech production. The sparse data that we have for children older than 60 months suggests that this gradual increase begins to level off after this point. If we had seen a non-linear shift in the frequencies of expression between 3 and 5, then an argument could have been made relating linguistic competency to Theory of Mind abilities. Finding no such shift, one could reasonably infer that the developing linguistic competencies that children have for expressions related to knowledge and belief are unrelated to their reasoning abilities in Theory of Mind tasks.

Second, there is no evidence to suggest a qualitative change in the *concepts* that children express related to knowledge and belief between the ages of 3 and 5. Looking at the individual frequencies for each of the 19 concept tags that were assigned to the corpus we see that the handful of concepts that account for the vast majority of tags increase in frequency at a constant rate from the very beginning of children's speech production. Very few expressions appear in this data related to other concepts that appear with slightly higher frequencies in adult discourse, and there is no evidence that linguistic competency is acquired for these concepts during this period of time either. If we had seen a change in the concepts that were being expressed between 3 and 5, then a different argument could have been made relating linguistic competency to Theory of Mind abilities. Finding no such change one could again reasonably infer a lack of a direct relationship between language-use and acquired reasoning abilities.

Together these two points argue against a strong relationship between linguistic competencies for expressions related to knowledge and belief and children's developing Theory of Mind abilities. This argument is particularly important in evaluating cognitive models that assume that Theory of Mind abilities and language abilities are enabled by representational mental models of the same type. If we assume that the sophistication of children's representational theories of knowledge and belief is closely related to the way that children express these concepts in language, then

there is little evidence to suggest that these representational theories change at all between ages of 3 and 5, when competency on the false-belief task develops. Accepting this assumption, the evidence in this paper would argue against any strong *conceptual change* account of Theory of Mind abilities where competency on the false-belief task is due solely to the acquisition of more sophisticated representational mental models. This evidence would argue instead for a *maturational* account, where competency on the false-belief task can be attributed to the development of new cognitive abilities for taking the perspective of other people or in the monitoring of one's own mental state between the ages of 3 and 5. One strong counterargument that could be made against this line of reasoning concerns the differences in the linguistic competencies between language production and language understanding. In analyzing transcript data consisting of words uttered by children, this study can make no claims regarding the linguistic competency that these children might have for *understanding* expressions related to knowledge and belief during the relevant periods of development.

Conclusions

The availability of large corpora of transcripts of children's speech production has afforded researchers the opportunity to investigate a wide variety of issues related to language acquisition. This paper has demonstrated that specific issues related to the acquisition Theory of Mind abilities can also be addressed using these corpora. By employing automated techniques for the tagging of expressions related to commonsense psychology we have been able to efficiently analyze data sets that are larger than could have been reasonably tackled given limited resources.

The specific interest of this paper was to determine if there was evidence for change in the linguistic competency in expressions related to knowledge and belief during developmental periods associated with acquired competency in the false-belief task (between 3 and 5 years of age). By using automated corpus analysis techniques, expressions related to knowledge and belief were identified across all datasets within the CHILDES corpus containing speech from normally developing monolingual English-learning children. By charting the frequencies of these expressions at different ages, it is evident that children steadily increase the frequency of expressions related to knowledge and belief at a constant rate from the beginning of their speech production. By tracking the production of expressions related to individual concepts, no qualitative changes in the conceptual content of these expressions over time is evident. These results argue against a strong relationship between linguistic competencies for expressions related to knowledge and belief and children's developing Theory of Mind abilities.

Acknowledgments

This paper was developed with funds of the Department of the Army under contract number DAAD 19-99-D-0046. Any opinions, findings and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the Department of the Army.

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