Talk, You're On Camera! Or, Comparing Naturalistic Audio and Video Recordings of Infants

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Abstract

Measurements of infants' experiences in their typical daily environments provide critical information about early development. However, the role of sampling methods in providing this information is rarely examined. Here we directly compare language input measures collected by hourlong video- and daylong audio-recording within the same group of 44 infants, at 6 and at 7 months. Month to month, our results are incredibly consistent, suggesting our methods obtain reasonable estimates of nouns in the input across the month-long gap. However, comparing recording-types, we find large differences across language quantity and lexical diversity, talker variability, utterance type, and referential transparency. Put briefly, video recordings featured far denser quantities of nouns, relatively more input from mothers, more questions and declaratives, and more talk about present objects. This suggests short video-recordings may inflate language input estimates, and should be used cautiously for extrapolation about common words, talkers, and situational/contextual features at larger timescales. Analyses based on counts and proportions often led to different conclusions; we suggest proportions may provide ill-advised compression of the information available to infants. Even when measures are standardized per unit time, or computed proportionally, hourlong video and daylong audio-recordings provide a fairly divergent picture of the input infants hear, and therefore learn from, in their daily lives. If our theories are to be held accountable to our observations, we suggest greater care be taken to unpack the ramifications of underlying methodological and analytic decisions for measuring infant language input.

Keywords: keywords

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Introduction

Researchers have studied development by observing infants experiencing their natural habitats for over a century (Taine, 1876,Williams, 1936). Over the past 20-30 years, written records have been increasingly supplemented with annotated audio and video recordings, which have described the linguistic, social, and physical landscape in which infants learn. Such data –often shared through repositories like CHILDES and Databrary–in turn provide a proxy for various "input" measures in theories of psycho-social, motor, and in particular, linguistic development (MacWhinney, 2001).

Furthermore, recent technological advances have made it feasible to collect longer, denser, and higher-quality recordings of infants' day-to-day lives, which aim to provide better approximations of infants' input and early language abilities (Bergelson & Aslin, 2017b,, Roy et al., 2015, Oller et al., 2010, Weisleder & Fernald, 2013, VanDam et al, 2016, inter alia.) Such naturalistic data seeks to reveal what infants actually learn from as they make use of their biological endowments and environmental resources.

While cutting edge technologies make collecting observational data ever easier, this growing toolbox increases researchers' decision load, with serious but underexplored side-effects. For instance, researchers must decide on recording modalities (e.g. audio, video, both), where, whom, and how long to record, and whether to capture structured or free-ranging interactions, with or without experimenters present. While any path through such decision-trees may lead to equivalent results, this is rarely tested directly. Problematically, this leads to research with theoretical conclusions built on equivalency assumptions that go unmeasured.

In recent work directly comparing observational sampling methods, Tamis-Lemonda et al. (2017) analyzed mother-infant behavior in 5-minute structured interactions, and 45 minutes of free play. Home sessions were video-recorded by an experimenter and transcribed. The results showed that relative to free play, in structured interactions infants generally experienced more language both in word-quantity (i.e. tokens) and word-variability (i.e. types) per minute. They also found that language quantity across contexts correlated, and that the peak five-minutes of the naturalistic interaction was similar to the 5-minute structured interaction. They conclude that sampling must be matched with research-question, cautioning that while brief samples may be appropriate for studying individual differences, extrapolations about overall language input from short samples must be made cautiously.

In contrast, work by Hart and Risley (1995) extrapolated extensively. Based on 30 hours of data per family (collected one hour per month for 2.5 years), these researchers estimated that by age four, children receiving public assistance (n=6) heard >30-million fewer words than professional-class children (n=13). While their results highlighting SES differences certainly merited (and received) follow-up (Noble et al, Fernald et al, 2013, inter alia), they have been criticized as an extreme over-extrapolation (Dudley-Marling and Lucas, 2009; Michaels, 2013).

Still other research analyzes base rates of certain linguistic phenomena, to provide in-principle proof of what young children can learn from their input (Tomasello, 2000; Lidz et al, 2003; Brent and Siskind, 2001). Here, the research question dictated what was deemed appropriate sampling. Problematically, for most exploratory work, "appropriate" sampling is hard to premeditate. For instance, practically any length of adult speech, across wide-ranging recording parameters will find function words (e.g. "of") at much higher rates than content words (e.g. "fork"). But for questions concerning infants' language input, it is largely unknown how methodological choices may bias our answers.

In the present study, we explore these issues, directly comparing hour-long video-recordings and daylong audio-recordings in a single sample of 44 infants, at 6 and at 7 months, as part of a larger study on early noun learning. We annotated concrete nouns (generally, objects, foods, animals, or body-parts) said to infants, or said loudly and clearly in their presence. We further annotated three properties previously linked with early language learning: (1) utterance-type, which provides syntactic and situational information (cf. Naigles & Hoff, Debaryshe, Brent & Siskind) (2) referential transparency, which clarifies whether the target of the spoken word is visually appreciable (Yurovsky et al, Trueswell et al, Bergelson & Aslin, 2017; Bergelson & Swingley, 2013), and (3) talker, which lets us quantify the range of speakers infants hear (Rost & McMurray, Bergmann et al, 2016, Cogsci).

This design sets up two overarching questions. First, we examine extrapolative validity: how well do the data from one video-recorded hour predict the absolute quantity and relative distribution of data in an entire audio-recorded day? Separating quantity and distribution is important given that (a) one may scale more robustly with recording length than the other and (b) we simply do not know how infants themselves aggregate their input. That is, count-based and proportional metrics may prove differentially predictive of language learning. Indeed, certain linguistic metrics like type-token ratio (a lexical-diversity metric) scale poorly with sampling length (Covington & McFall, 2010), but yet, along with their "absolute" counterparts (type and token counts), predict language development (e.g. Pan et al, 2005; Huttenlocher et al, 2001;2010; Rowe 2012, Hoff and Naigles, 2002). For others metrics, we simply do not know how they scale with recording-length, or whether relative or absolute quantities predict learning better (or even differentially). Here we chart some points within this underspecified space, probing how robust linguistically-relevant measures are across two sampling methods of infants' everyday experiences.

Second, we assess input-stability within sampling method: do infants receive quantitatively different language input when we audio- or video-record at 6 months compared to when we do so four weeks later? Put otherwise, are there effects of "initial" vs. "subsequent" observational recordings, and do these vary by recording length and modality? Given that there are no major developmental milestones between 6 and 7 months, we predict strong convergence across time-points. Several accounts are compatible with cross-month differences, including the possibility that caregivers simply behave differently at initial versus subsequent home visits.

Thus, our main goal was to compare language input young infants receive across four key properties (frequency, utterance-type, referential transparency, and talker), as measured by an hour of video and a (separate) full-day audio-recording, each at two time-points. This seemingly methodological question has deep implications for developmental theory: we examine how sampling and aggregation approaches may alter conclusions about the linguistic input that in turn drives early development.

Methods

Participants

Participants were recruited from an existing database of families from local hospitals, or who heard about the BabyLab from friends, family, and outreach. Forty-six participants enrolled; two dropped out in the early stages of the project leaving 44 infants in the final sample. All infants were full-term (40 ± 3 weeks), had no known vision or hearing problems, and heard >75% spoken English in the home. Participants were 95% white; 75% of mothers had a B.A. or higher. The families were enrolled in a yearlong study that included monthly audio- and video-recordings, as well as in-lab visits every other month. Here we report on the home recording data from the first two timepoints (6 and 7 months) of this study, for which participants were compensated $10; see table XX.

Procedures

Participants gave consent at an initial lab visit for the larger study through a process approved by the University of Rochester IRB. Questionnaires about various aspects of the family’s and infant’s background conducted during lab visits, not germane to the present analysis, are reported elsewhere (Bergelson & Aslin, 2017b; Laing and Bergelson, under review). Four recordings were collected for each infant: an audio- and video-recording at six and at seven months. Each recording was on a different day. See table XX.

Audio-video release forms were given to parents and collected after the audio and video recordings for the month were complete. Parents could opt to share the data with other authorized researchers and/or to have excerpts used for academic presentation. The released audio and video files can be accessed by registered researchers on Databrary.

Video-Recordings

Researchers visited infants' homes each month to video-record a typical hour of infants life from their own perspective. To achieve this, infants were outfitted with a hat or headband affixed with two small, lightweight Looxcie cameras (22g each). One camera was oriented slightly down and the other slightly up, to capture most of the infant's visual field (verified by Bluetooth with an iPad/iPhone during setup). A standard camcorder (Panasonic HC-V100 or Sony HDR-CX240) on a tripod was set up in a location that could best capture the infant. Parents were asked to move this camera with them if they changed rooms. After set-up, experimenters left for one hour.

Audio-Recordings

Audio-recordings captured a full day (up to 16 hours) of infants' language input. Parents were given vests with a small chest-pocket, and LENAs (LENA Foundation, Boulder, CO), small audio-recorders (<60g) that fit into the vest pocket. Parents were asked to put the vest and recorder on babies from when they awoke to when they went to bed (with the exceptions of naps and baths). Parents were permitted to pause the recorder at any time but were asked to keep such pauses minimal.

Data Processing

Details of our entire data processing pipeline are on our lab wiki (https://osf.io/cxwyz/wiki/home/). Videos were processed using Sony Vegas and in-house video-editing scripts. Footage was aligned in a single, multi-camera view before manual language annotation in Datavyu. Audio recordings were initially processed by LENA proprietary software, which segments and diarizes each audio file; this output was then converted to CLAN format for further processing and manual annotation. Through in-house scripts, long periods of silence were demarcated in these CLAN files (e.g. when the audio vest was removed or during naps). The CLAN files were then used for manual language annotation.

Language Annotation

Recordings were next annotated by trained researchers. The "sparse annotation" entailed marking each concrete noun heard by the child. This includes words directed to or easily overheard by the child (e.g. words directed at a sibling next to the infant), but not distant or background language (e.g. background television). We operationalized "object words" as concrete, imageable nouns (e.g. shoe, arm). For each object word, we included the word (as said by the speaker, e.g. "teethies"), and lemmatized to it's "basic level" or dictionary form (e.g. tooth), along with three properties: utterance-type, object presence, and talker. Utterance-type classified each object word utterance as declarative, question, imperative, reading, singing, short-phrase, or unclear. Short-phrase utterances include words in isolation and short, simple noun phrases (e.g. "the red ball" or "kitty's paw"). Object-presence was a binary measure of whether the object was present and attended to. Lastly, the word's talker was recorded, including live interlocutors and electronics: mother, brother, toy, etc.

We assessed intercoder reliability on a random contiguous 10% of the annotations in each file.

Results

Results

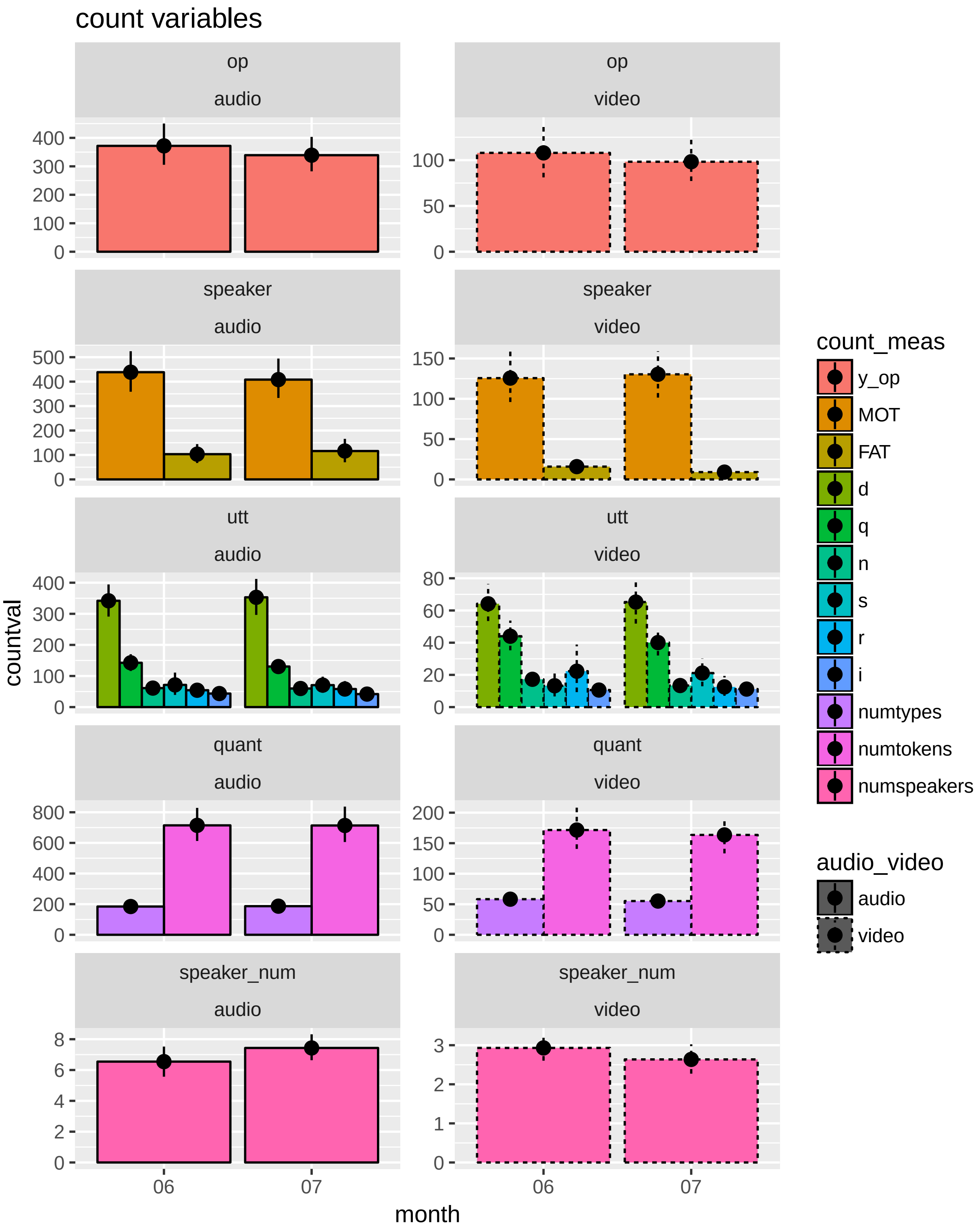
Analysis Plan

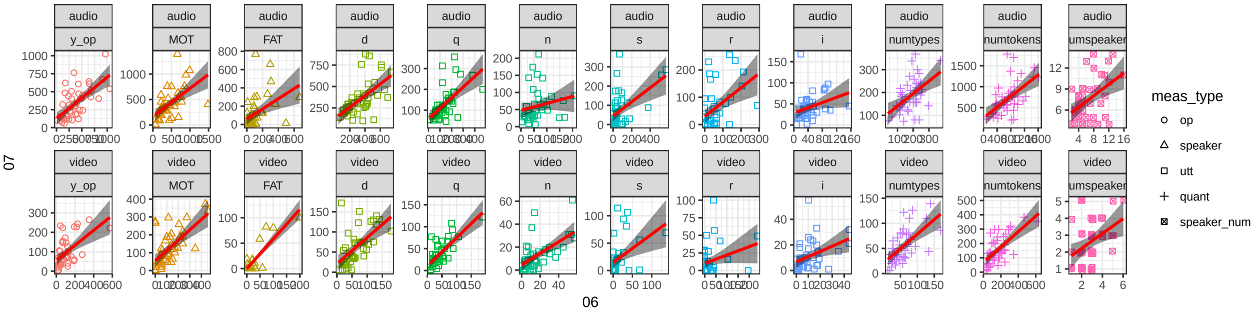
Based on the coding scheme above, we derived count (n=12) and proportional (n=10) measures from each recordings' annotations for each child (n=44), recording-type (audio, video), and month (six, seven). See Table XX. We also normalized the count measures by recording length; further details are below. We initially created multi-level models, with each of the 22 measures as the dependent variable, recording-type and month as fixed effects, and participant as a random effect (i.e. dv ~ recording_type + month + (1|subj)). Month was not a significant predictor in any of the 22 models; recording-type was in 17/22 models (see S.I.). However, since many of the models showed structured (generally funnel-shaped) residuals that limited interpretation across measures, we instead report a simple set of nonparametric analyses.

For all recording type and month comparisons, we look at whether our measures *differed* significantly (by two-tailed, paired Wilcoxon Test), and *correlated* significantly (by Kendall Rank Correlation) across the given groups. This approach lets us compare, e.g., whether the proportion of declaratives is indistinguishable in our audio and video recordings independently of whether these values are correlated across recording-types. We applied Holm's p-value adjustment for multiple comparisons (Holm, 1979), for each set of Wilcoxon and Kendall tests. For instance, comparing the 12 count measures for month six vs. seven within audio recordings by Wilxocon test is one "set". With our analysis plan of 2(count or proportional) x 2(audio or video) x 2 (six or seven month) x 2(Wilcoxon Test or Kendall correlation), we applied this p-value adjustment to 15 further sets.

Count Measures, Month 6 vs. 7

We first analyzed the 12 count measures in month six versus seven, by recording-type. Across children, none of the 12 differed by month within audio recordings (all adjusted-p>.05), or within video recordings (all adjusted-p>.05.) Testing the correlations, all 12 count measures correlated significantly month-to-month for audio (Kendall's tau ranged from 0.29 - 0.52, all adjusted-p<.05), and 11/12 did so for video (Kendall's taus ranged from 0.29 - 0.60, all adjusted-p<.05), excluding number of nouns heard in reading (adjusted-p>.05). Thus, within recording type, the count-based metrics of the object words infants heard were statistically equivalent in month six and seven, and correlated significantly within children month-to-month (except 1/24 correlations); see figure XX. This suggests that parents are acting naturally, or at least consistently, during our home recordings each month.





Count Measures, Audio- vs. Video-recordings

We next assessed our count measures across recording-types, examing how noun input scaled between hour-long video-recordings and daylong audio-recordings. Modally, videos were an hour (62 min, M=60.79, SD=6.31, R=27.9-74.9 min), and audio-recordings were 16 hours (960 min, M=858.41, SD=119.41, R=635-960 min), the maximum capacity of the LENA device. While determining the exact onsets and offsets of naps from audio alone is not possible, by removing the "silent" portions of the recordings (see Methods), we estimated an upper-limit on infants' awake (i.e. non-silent) time (Mode = 10.90, M = 603, SD=106.8, R=385.2-951 min). This comports with established norms for 6–8-month-olds in the US (Mandel et al, 2010), which are 3 hours of daytime sleep, and 10 hours of nighttime sleep. Thus, 16 hours of recording beginning when the child wakes up should capture ~11 daytime waking hours, in line with our silence demarcations. Infants were always awake during video recordings (save one infant, who fell asleep before the recording-hour ended; that video was stopped at sleep onset).

```
##   month aboost_min aboost_awakemin aboost_types aboost_tokens
## 1    06      13.89            9.88         4.05          5.79
## 2    07      14.82           10.45         4.65          6.03
##   aboost_speakers aboost_MOT aboost_FAT aboost_d aboost_q aboost_i
## 1            2.61       4.09       4.66     6.89     4.11     9.36
## 2            3.49       4.33      48.53     8.72     5.06    10.98
##   aboost_s aboost_r aboost_n aboost_op       comp
## 1     8.17     2.18     5.53      5.68 mean_aboost
## 2    10.31     8.64     8.44      6.07 mean_aboost
```

```
##   month aboost_min aboost_awakemin aboost_types aboost_tokens
## 1    06       2.19            1.75         2.46          4.06
## 2    07       4.19            3.99         3.63          5.10
##   aboost_speakers aboost_MOT aboost_FAT aboost_d aboost_q aboost_i
## 1            1.74       3.13       3.77     4.77     3.15    12.52
## 2            2.13       3.74     139.61     8.76     5.60    27.00
##   aboost_s aboost_r aboost_n aboost_op      comp
## 1    10.20     2.11     4.88      5.55 sd_aboost
## 2    24.59    14.05    10.45      8.25 sd_aboost
```

To examine how the hour-long video data "scale" to day-length data descriptively, we divided the 12 audio count metrics by the 12 video count metrics for each child, to derive "audio-boost" scores. This showed that the audio-recordings were ~14x longer than the videos, or 10x longer if only "non-silent" portions of the audio-recording are included. However, rather than a concomitant 10-fold increase in our count metrics (as would be expected if the video captured a "representative" hour of the day), the boost was closer to fivefold across measures; see Table XX. This suggests that the videos, by and large, had a denser concentration of nouns across our measures than did the audio recordings.

Notably, "zero" values (e.g. recordings in which there were no nouns heard in singing) were omitted from the audio-boost computations given that they result in undefined values for a given child in a given month. The majority of variables had at least one such value, with over 1/3 of video recordings lacking instances of nouns heard in singing, reading, or by fathers each month; see Table XX.

```
## # A tibble: 2 x 11
##    month v_MOT a_FAT v_FAT   v_q   v_i   a_s   v_s   a_r   v_r   v_n
##   <fctr> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1     06  0.16  0.05  0.52  0.00  0.07  0.07  0.32  0.25  0.55  0.02
## 2     07  0.09  0.09  0.75  0.02  0.07  0.07  0.34  0.25  0.50  0.07
```

```
## # A tibble: 1 x 8
##   v_MOT a_FAT v_FAT   v_i   a_s   v_s   a_r   v_r
##   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1  0.09  0.02  0.52  0.02  0.02  0.11  0.16  0.34
```

We next normed our count values by the number of minutes in each. For example, if an infant heard 500 noun-tokens in 800 minutes of non-silent audio-recording, and 200 in 60 minutes of videos, this was normed to .62 and 3.3 noun-tokens per minute, respectively. Unlike for the audio-boost calculation, this allows us to retain zero values, rendering more readily interpretable results across our count and proportional measures.

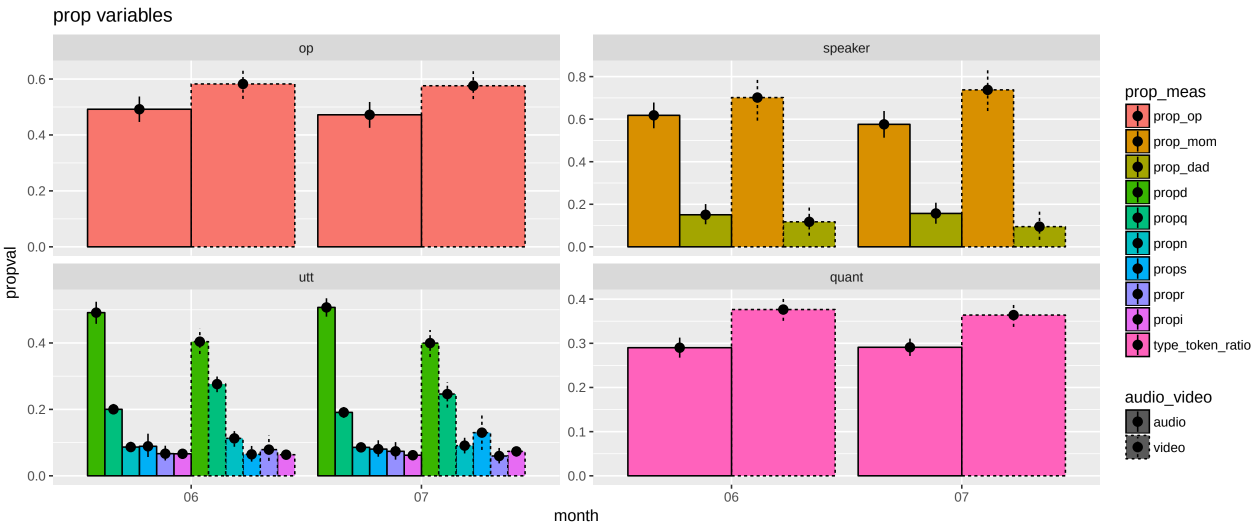
```
## # A tibble: 12 x 3
##      norm_meas  `06`  `07`
##         <fctr> <dbl> <dbl>
##  1        y_op   2.9   2.8
##  2         MOT   2.9   3.2
##  3         FAT   1.5   0.8
##  4           d   1.9   1.8
##  5           q   3.1   3.0
##  6           n   2.9   2.2
##  7           s   1.8   3.0
##  8           r   4.0   2.1
##  9           i   2.4   2.8
## 10    numtypes   3.1   2.9
## 11   numtokens   2.4   2.3
## 12 numspeakers   4.4   3.6
```

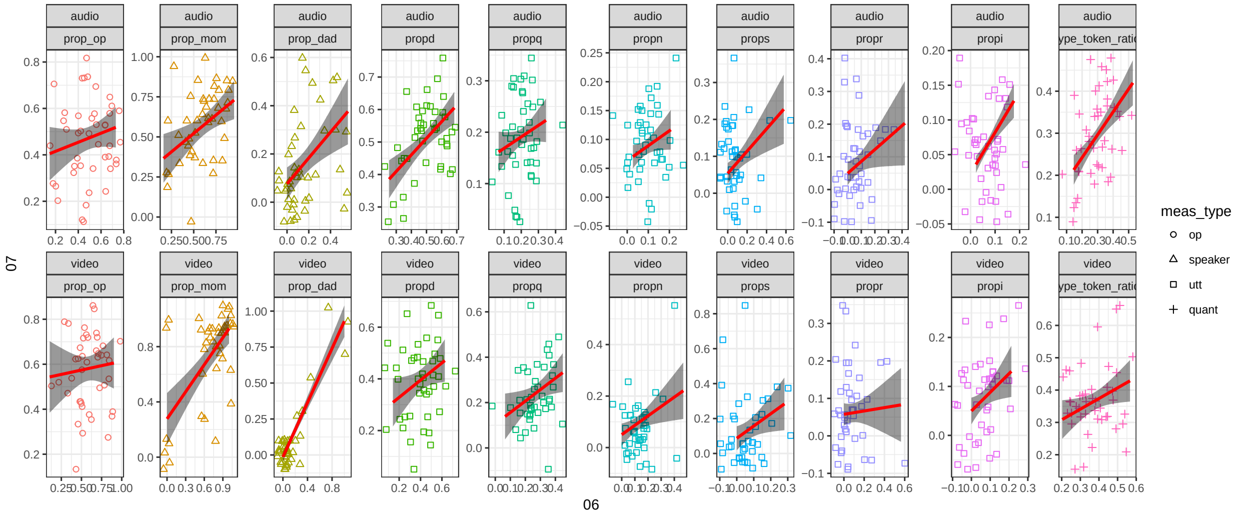
With the normed data, we found identical patterns when looking within month six and seven: /12 of our count-based metrics (in each month) occurred at significantly lower rates in audio recordings than video recordings (adjusted-p<.05). The three that were statistically indistinguishable were nouns/minute produced (1) by fathers, (2) in reading, and (3) in singing (all adjusted-p>.05). These same three measures had a large number of zero values; see table XX. We return to the topic of unattested low-frequency events in corpora in the discussion.

The pattern of correlations across recording-types was mixed: in month six, audio vs. video normed count data only correlated significany for 3/12 metrics, which were all utterance-type measures: declaratives (tau = 0.44), questions (tau = 0.33), and imperatives (tau = 0.30; all 3 adjusted-p<.05). For month seven, 11/12 metrics correlated in audio vs. video data; number of nouns per minute heard in singing did not (excluding singing, 0.27 - 0.53, all adjusted-p<.05). See table XX and figure YY.

Proportion Measures, Month 6 vs. 7.

Turning to the 10 proportion measures, as with the count measures, there were no significant differences between month six and seven within audio- or within video-recordings (all adjusted-p>.05). The pattern of correlations differed somewhat from the count measures: for the audio-recordings, 7/10 proportional measures correlated from month 6 to 7 (for these seven: Kendall's tau range: 0.31-0.46, adjusted-p<.05; for object co-presence, questions, and short-phrases adjusted-p>.05). For videos, only proportion of input from mom and from dad correlated significantly from month 6 to 7 (Kendall's tau = 0.45 and 0.63, respectively; adjusted-p<.05). Thus, overall, the proportional metrics were indistinguishable month-to-month within recording-type, but the correlations between the proportional measures across children at month six and seven were variable, especially for video-recordings.





Proportion Measures, Audio- vs. Video-recordings

Across recording-types, proportional measures differed more substantively than count measures; see figure XX. At six months, 4/10 proportional measures differed significantly between audio- and video-recordings (type-token ratio, and the proportion of object presence, declaratives, and questions, all adj-p<.05), while at seven months, 6/10 did so (the same four as in month six, plus input from mothers and fathers; all adj-p<.05). See Figure XX.

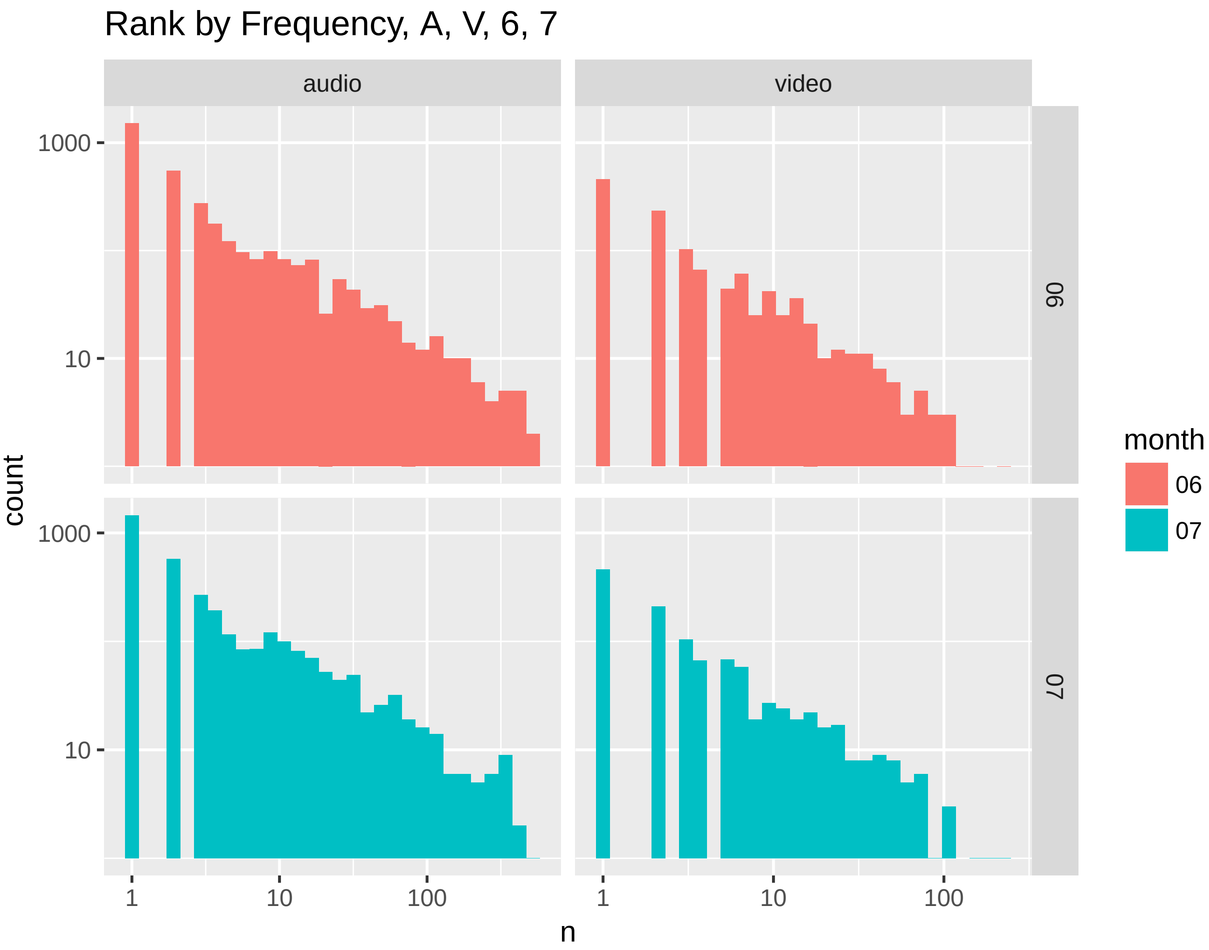
Descriptively, videos featured object presence more than audio-recordings ($M_{\Delta} = \%$), likely reflecting a narrower range of activities during video recording. Videos also had a higher type-to-token ratios (i.e. more lexical diversity): $M=$ vs. for audio-recordings, consistant with previous work (Covington & Fall, 2010).

Across utterance-types, the overall distributions of nouns in audio- and video-recordings were similar: the majority of the noun input was declaratives, followed by questions, with the remaining input spread across imperatives, reading, singing, and short-phrases; see Figure XX. However, audio-recordings featured relatively more declaratives and fewer questions than videos (, and %, respectively). Finally, in month seven, mothers talked % less in audio than video, and fathers talked % more.

Turning to correlations across recording-types, in month six only the proportion of imperatives reached significance (Kendall's tau =, adj-p<.05). At seven months, three of the variables that differed significantly also correlated significantly (proportion of noun input from fathers and mothers, and in declaratives), along with the proportion of nouns heard in reading, (all four adj-p<.05, Kendall's tau range: 0.30 - 0.35).

Noun Frequency and Prevalence

We conclude with a set of highly exploratory analyses at the word level, which aim to provide a first-pass characterization of whether audio and video recordings captured the same nouns and the same relative frequencies by examining word frequency across each month, recording type, and infant. The distribution of nouns in our recordings was zipfian: of the 5801unique object words (3137 lemmas) heard across months and recording types, only 2482 (960 lemmas) were heard more than once (see figure XX).


Rank by Frequency, A, V, 6, 7
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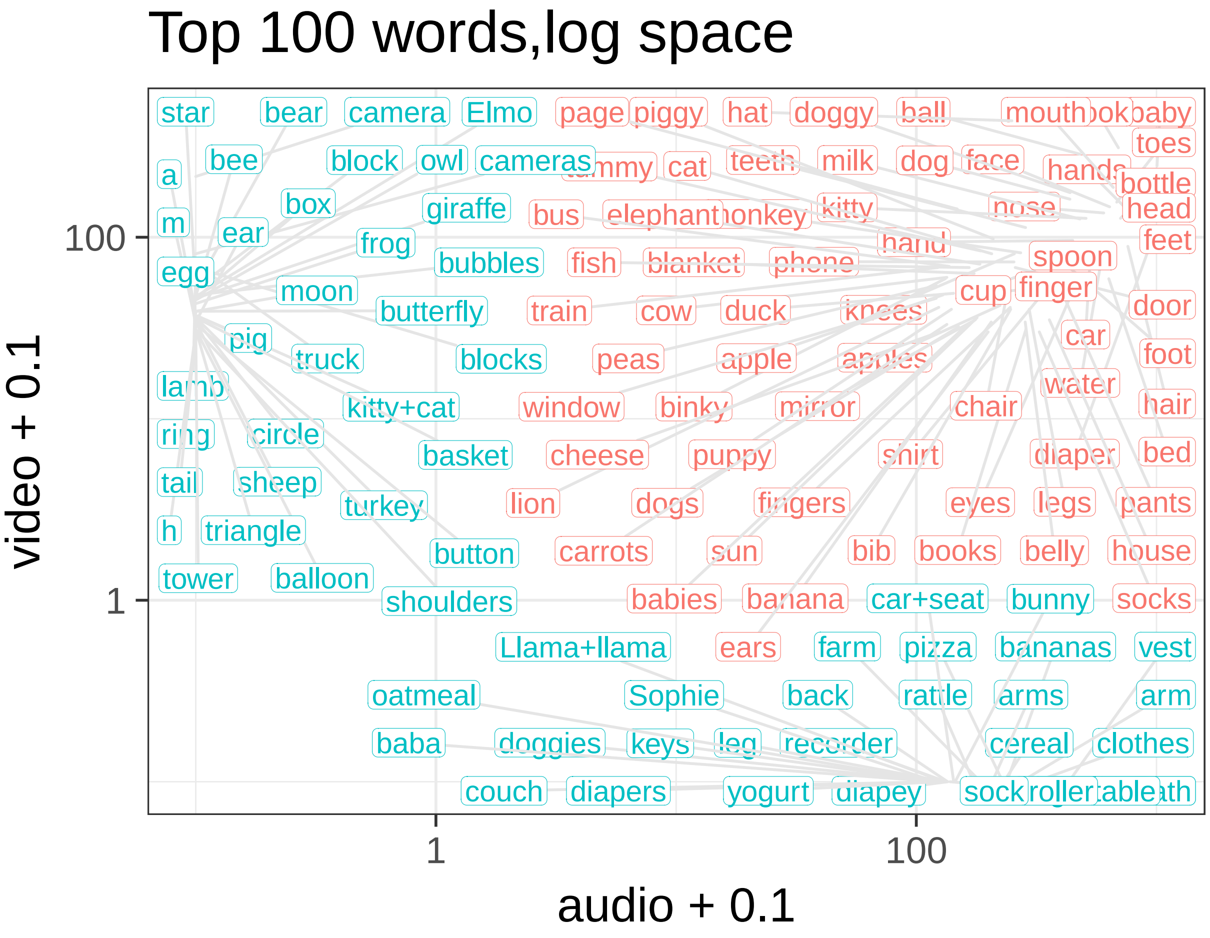
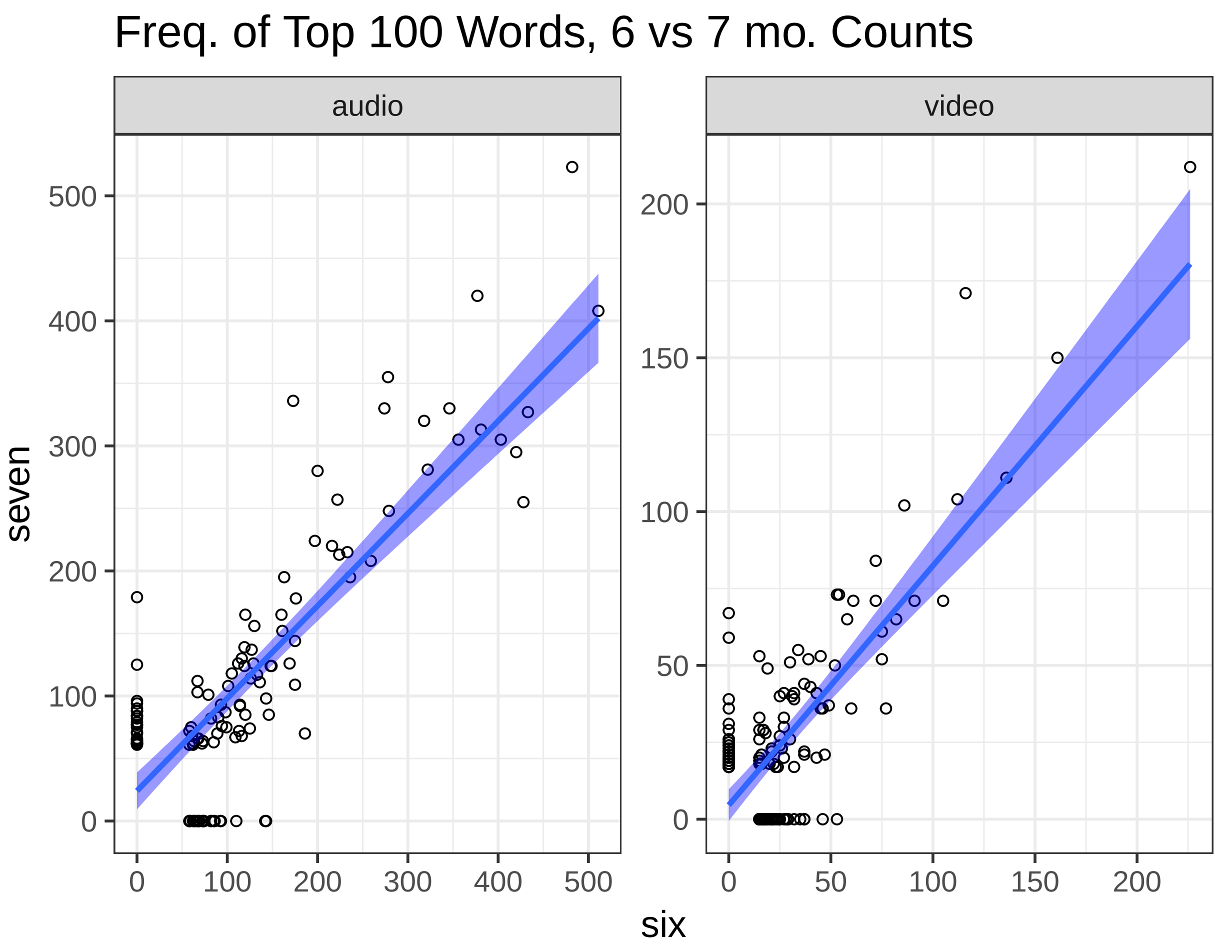


Collapsing month, we examined the top 100 most frequent nouns from audio- and video-recordings (n=136 due to ties, n=68 without words that occurred zero times in one recording-type). Frequency across recording-types correlated significantly (Kendall's tau: 0.39, p<.0001,) even with zero-frequency words included (Kendall's tau: 0.25, p<.0001; see figure XX). Further, we found numerically stronger correlations month-to-month than across recording-types within month (month 6 audio vs. video: tau = 0.15, month 7 audio vs. video: tau = 0.15, month 6 vs. 7 audio: tau = 0.50, month 6 vs. 7 video: tau = 0.26, all adjusted-p<.05; see figure XX). Thus, at the word-level too, month-to-month measures appear more stable than cross-recording-type measures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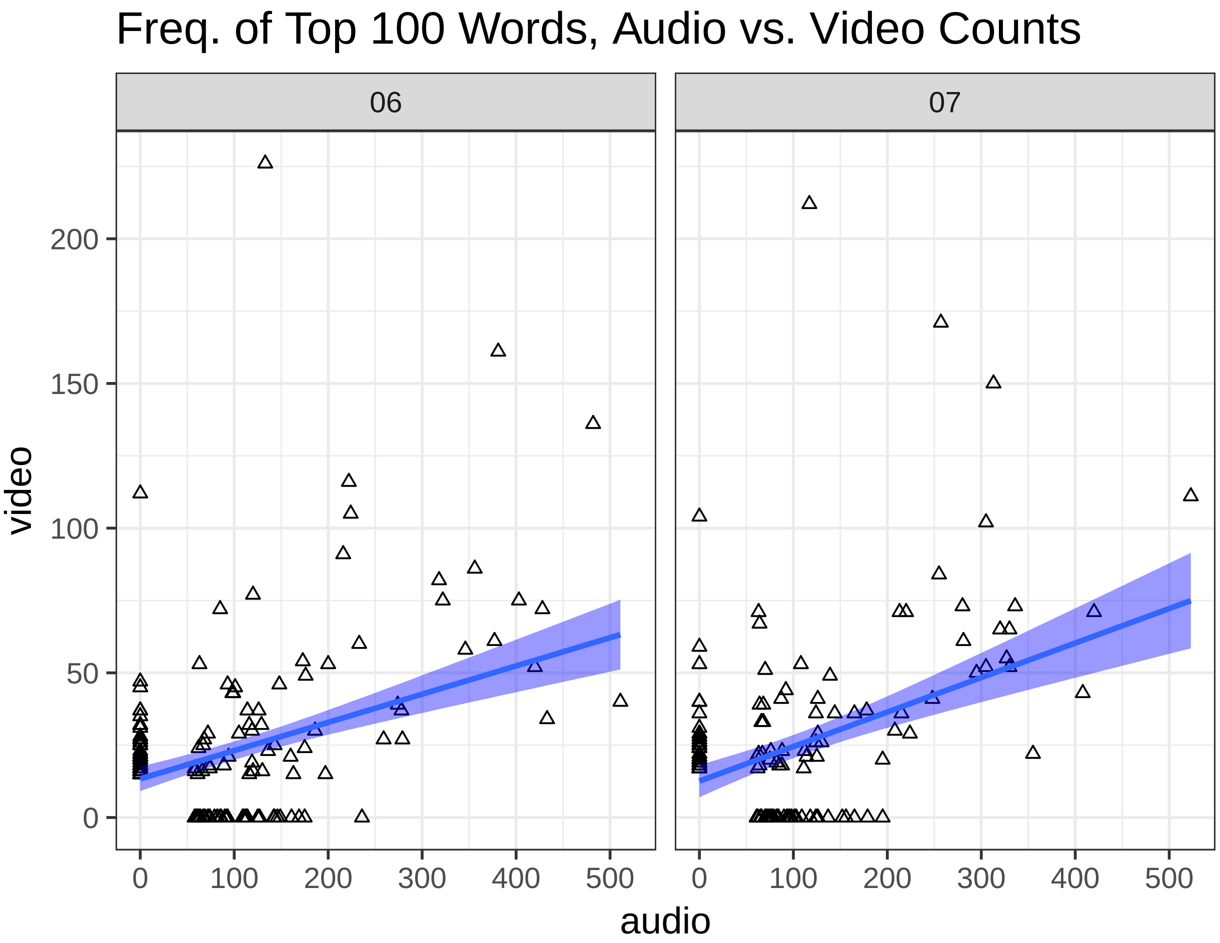

Finally, looking at just the top ten words by month and recording-type, we again find greater consistency across months than recording-types (see Figure XX and Table XX). Indeed, top words within recording-type were largely overlapping, while only two words overlapped on all four lists (book and baby). Furthermore, characterizing how words were spread across infants and months, we find that the top audio words were far more common across families than the top video words were (see figure XX). Thus, daylong audio-recordings appear to render more stable high-frequency words across families and across months than do video-recordings.

Discussion

References

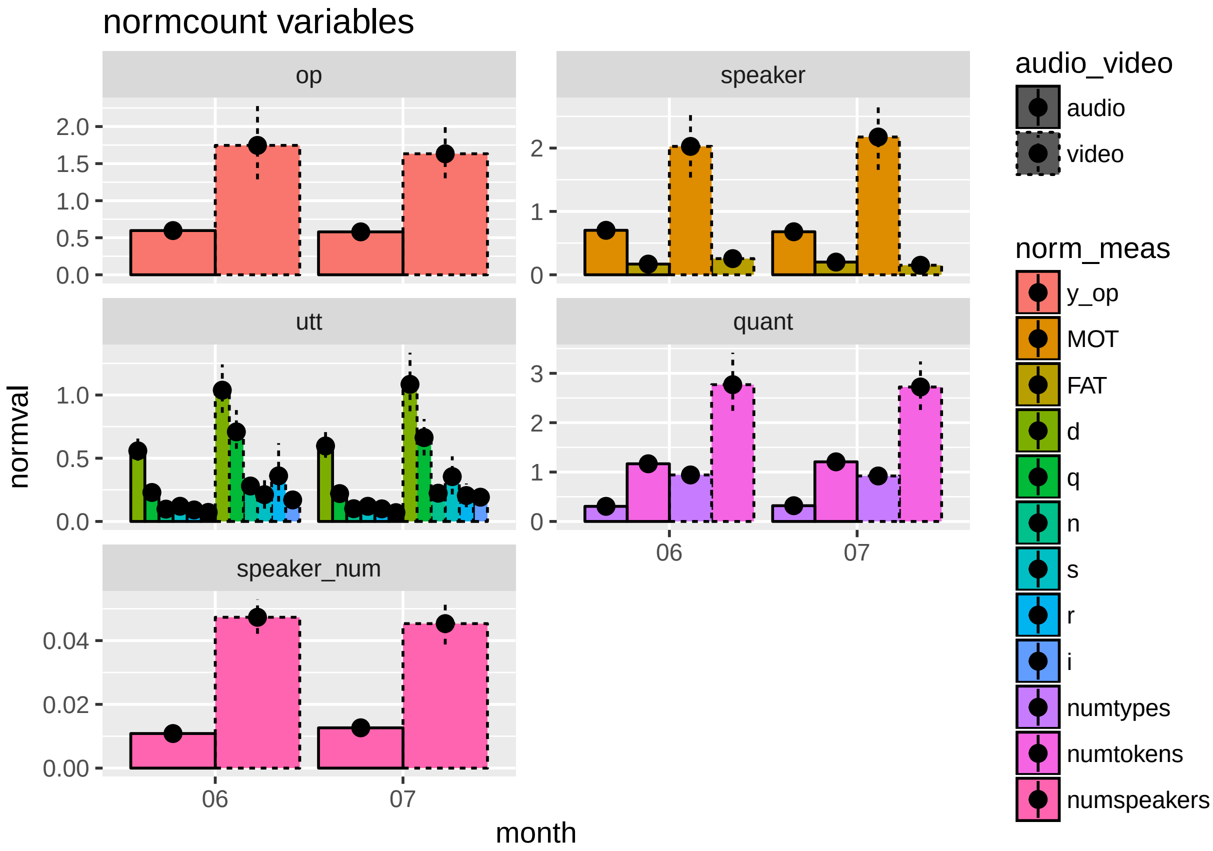
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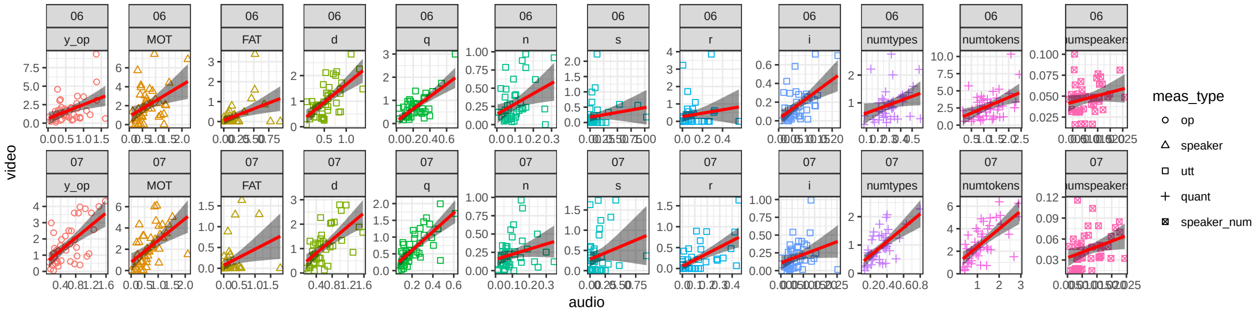
Figure 1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speaker_num

Figure 2

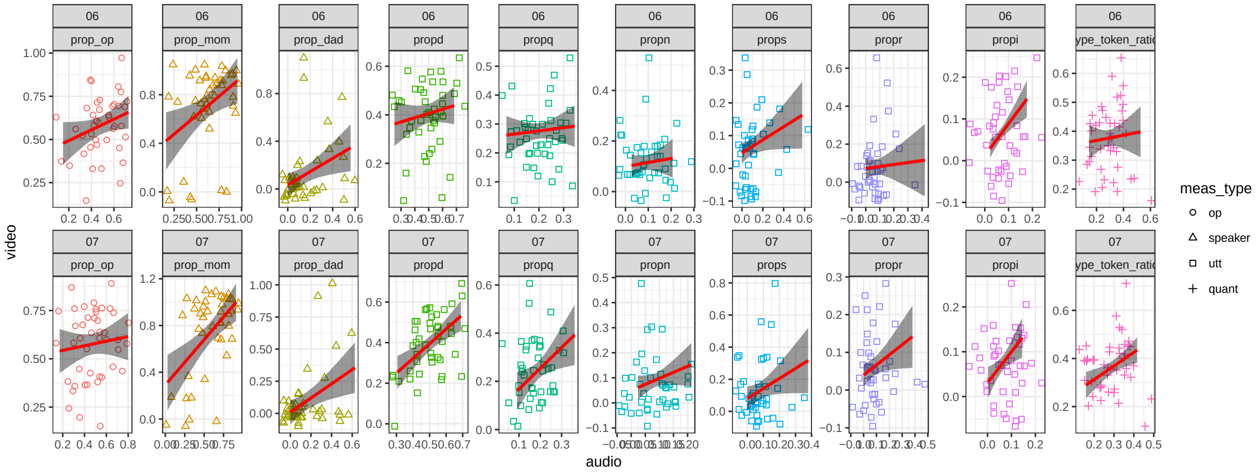
06
prop_op
06
prop_mom
06
prop_dad
06
propd
06
propq
06
propn
06
props
06
propr
06
propi
06
ype_token_ratio
07
prop_op
07
prop_mom
07
prop_dad
07
propd
07
propq
07
propn
07
props
07
propr
07
propi
07
ype_token_ratio
video
audio
meas_type
op
speaker
utt
quant

Figure 3

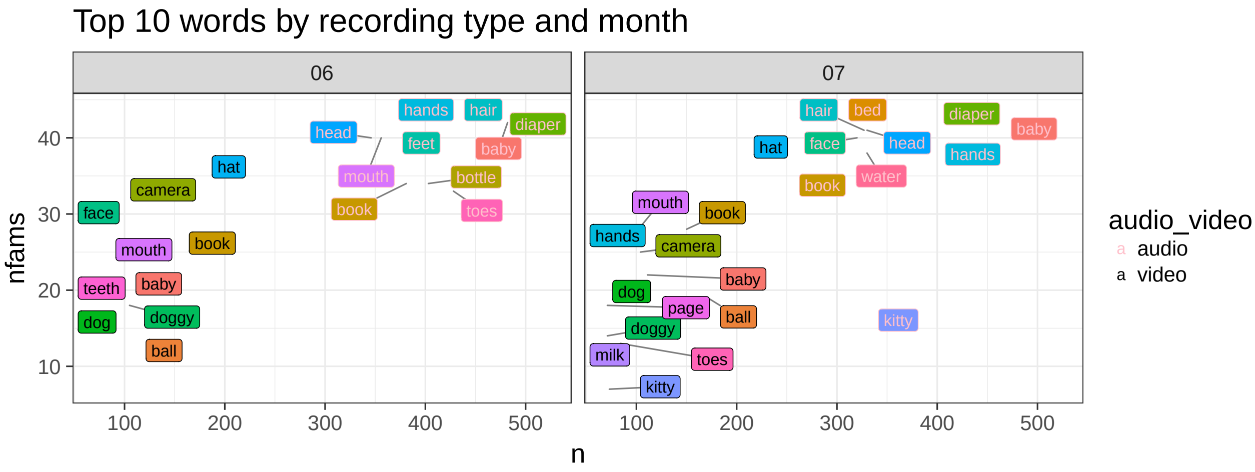
Top 10 words by recording type and month
06
07
nfams
n
10
20
30
40
100
200
300
400
500
audio_video
a audio
a video
hands
hair
diaper
head
feet
baby
hat
mouth
bottle
camera
book
toes
face
mouth
book
teeth
baby
doggy
dog
ball
hair
bed
diaper
baby
hat
face
head
hands
book
water
mouth
book
hands
camera
baby
dog
page
ball
kitty
doggy
milk
toes
kitty

Figure 4