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Does sound structure affect word learning? An eye-tracking study of Danish learning toddlers

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ABSTRACT

Previous research has shown that Danish-learning children lag behind in early lexical acquisition compared with children learning a number of other languages. This delay has been ascribed to the opaque phonetic structure of Danish, which appears to have fewer reliable segmentation cues than other closely related languages. In support of this hypothesis, recent work has shown that the phonetic properties of Danish negatively affect online language processing in young Danish children. In this study, we used eye-tracking to investigate whether the challenges associated with processing Danish also affect how Danish-learning children between 24 and 35 months of age establish and learn novel label–object mappings. The children were presented with a series of novel mappings, either ostensively (one novel object presented alone on the screen) or ambiguously (one novel object presented together with a familiar one), through carrier phrases with different phonetic structures (more vs less opaque). Our results showed two main trends. First, Danish-learning children performed poorly on the task of mapping novel labels onto novel objects. Second, when learning did occur, accuracy was affected by the phonetic opacity of the speech stimuli. We suggest that this finding results from the interplay of a perceptually challenging speech input and a

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slower onset of early vocabulary experience, which in turn may delay the onset of word learning skills in Danish-learning children.

Introduction

Cross-linguistic studies of the trajectories of early vocabulary acquisition have shown that different languages are learned at different rates, with children's average vocabulary sizes differing by as much as 60% across language groups during their first 2 years of life (Bleses et al., 2008a, 2008b). This variability in learning rate is likely to be driven by, among other things, structural differences across languages (Bates, Devescovi, & Wulfeck, 2001; Stoel-Gammon, 2011). Children learning Danish, for example, show a slower lexical development rate than children learning a number of other languages, possibly as a consequence of the opaque phonetic structure that characterizes Danish speech (Bleses, Basbøll, Lum, & Vach, 2011; Bleses, Basbøll, & Vach, 2011; Bleses et al., 2008b). The opaque nature of the Danish speech signal has been argued to make the language especially hard to process and, as a consequence, to delay lexical acquisition in Danish-learning children (Bleses & Basbøll, 2004; Bleses & Trecca, 2016; Bleses et al., 2008b).

The idiosyncratic sound structure of Danish results mainly from the interplay of two pervasive phonological processes (see Basbøll (2005) and Grønnum (2003), for detailed accounts). First, and most important, a number of Danish consonants undergo extensive weakening (or lenition) in unstressed syllables. Weakening is manifested as loss of aspiration/affrication (e.g., [kʰ] → [g̊]), loss of closure (e.g., /b g/ → [u̯], /d/ → [ð̞]), and, more generally, in many consonants being realized as semivowels (e.g., /r/ being consistently realized as [ɐ̯] word-finally as in *biler*, [ˈbiˀlɐ̯], "cars"). As a result, Danish speech is characterized by frequent uninterrupted sequences of *vocoids* (phonetically defined vowels [i.e., vowels and semivowels] vs *contoids* [phonetically defined consonants]), both word-internally and across word boundaries. Second, the neutral vowel /ə/ (schwa), occurring in unstressed syllables, is commonly assimilated to neighboring phonemes (e.g., *gade,* street, [ˈ g̊ æːð̞ə] → [ˈ g̊ æːð̞ð̩]). Together, consonant weakening and schwa assimilation give Danish speech an unusually monotonous sonority profile (i.e., the distance in acoustic saliency between different segments in a syllable is typically less marked than in other related languages) and frequently lead to the loss of entire syllables (Grønnum, 2003).

This combination of segmental and syllabic reductions results in a speech signal in which syllable and word boundaries are often less explicitly marked than in other closely related languages (Basbøll, 2005; Bleses et al., 2008b). The effect becomes evident when comparing Danish words or sentences with cognates from other Scandinavian languages, as shown in Fig. 1. The long speech sequences with few or no contoids that characterize Danish—which are manifested acoustically as speech sequences with few or no interruptions in voicing—have been hypothesized to be harder to segment than sequences of alternating contoids and vocoids (e.g. Gooskens, van Heuven, van Bezooijen, & Pacilly, 2010; Grønnum, 2003). This is because the alternation of contoids and vocoids makes syllable and word boundaries perceptually more salient (e.g. Oller, 2000; Wright, 2004,) and arguably because it is easier to segment speech by computing statistics over contoids than vocoids (e.g. Bonatti, Peña, Nespor, & Mehler, 2005). Furthermore, prosodic cues are significantly less prominent in Danish than in other closely related languages, mainly because of the lack of compulsory sentence accents, which may contribute to making Danish speech particularly hard to process (Grønnum, 2003; see also Gooskens et al., 2010).

The hypothesized difficulty of segmenting Danish received support from a recent eye-tracking study of speech processing in Danish-learning 2-year-olds. The study found that children needed a longer time to orient to a known target object on the screen (*abe* [monkey], *and* [duck], *bamse* [teddy bear], *bil* [car]) when prompted to do so by a sentence that was highly vocalic/reduced as a consequence of the phonological processes described above (*Her er ____!*, [ˈheʌ̯ æ], "Here is the ____!" with

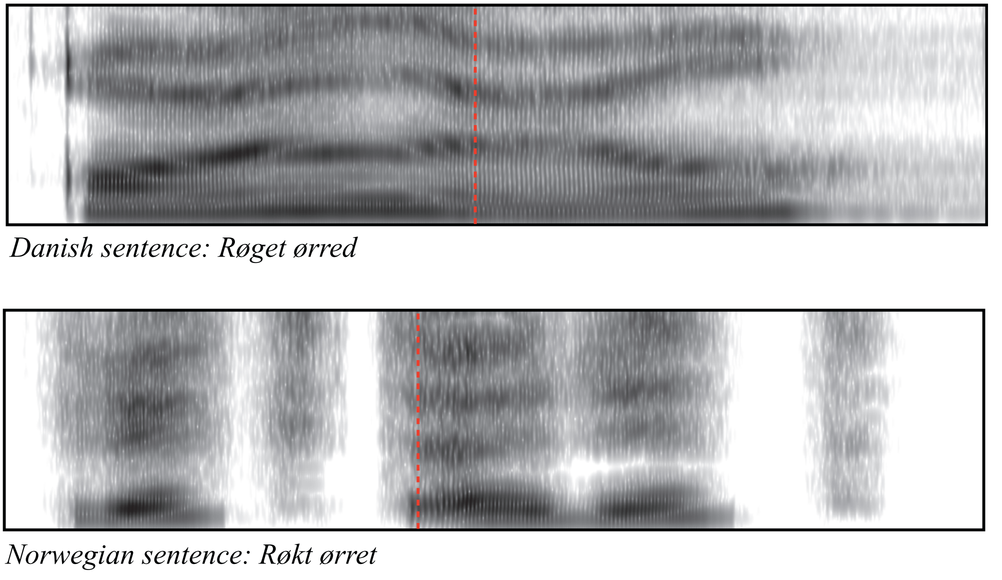

Fig. 1. Spectrograms for the Danish (top) and Norwegian (bottom) cognate phrases *røget ørred* and *røkt ørret* (English: smoked trout). The red dotted lines indicate the approximate location of the two word boundaries. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contoid-vocoid-vocoid-vocoid [CVVV] structure) compared with a sentence with a more consonantal/unreduced structure (e.g., *Find ____!*, [ˈfe̞nˀ], “Find the ____!” with CVCC structure) (Trecca, Bleses, Højen, Madsen, & Christiansen, submitted for publication). In addition, studies have shown that the Danish sound structure also seems to affect processing and acquisition of morphology: Bleses, Basbøll and Vach (2011) showed that Danish-learning children acquire the regular past tense ending *-ede* [əð̞ə] (which is consistently reduced and not acoustically salient, as in *at bade,* to bathe, [ˈbaːð̞ə] → *badede,* I bathed, [ˈbaːð̞əð̞ə] in distinct form → [ˈbaːð̞ː] in casual speech) later than their Scandinavian neighbors (e.g., in Swedish, where the suffix *-ade* is pronounced more clearly, as in [bɑːdɑdə]). Similarly, Kjærbæk, Christensen, and Basbøll (2014) showed that Danish plural suffixes that are more prone to phonetic reductions (e.g., *tov, tove,* “rope, ropes,” [tʌw tʌwə], in which the /ə/ is often dropped) are acquired later than suffixes that are not susceptible to reduction. This has been claimed to affect word learning negatively by impeding the formation of stable phonological representations of words (Bleses & Basbøll, 2004; Bleses, Basbøll and Vach, 2011).

Taken together, these studies suggest that the opaque sound structure of Danish may at least partly account for the slower rate of lexical development observed in Danish-learning children. Still, whether the difficulty associated with the processing of Danish speech may have a direct impact on how Danish-learning children learn new words remains an open empirical question. In an effort to answer this question, we investigated how Danish-learning children at 24–35 months of age learn novel label–object mappings using an eye-tracking procedure. Addressing this question can help us to understand how Danish-learning children tackle the process of learning new words given the challenges associated with their ambient language.

Using eye-tracking to study word learning

We chose to assess the impact of the Danish sound structure on children’s ability to establish and learn novel label–object mappings using the *looking-while-listening* (LWL) paradigm (Fernald, Zangl, Portillo, & Marchman, 2008), a preferential looking procedure, for consistency with a previous study of word recognition in Danish-learning toddlers (Trecca et al., in preparation). Preferential looking/-

pointing methods are commonly used in studies of both online processing of familiar words/sentences (e.g. Fernald & Marchman, 2012; Fernald, Marchman, & Weisleder, 2013; Fernald, Thorpe, & Marchman, 2010; Hurtado, Marchman, & Fernald, 2008) and of novel word learning. In the latter case, many preferential looking/pointing studies have investigated how children establish mappings between novel labels and novel objects after only few exposures, a skill known as *fast mapping* (e.g. Carey, 1978, 2010; Carey & Bartlett, 1978). Fast mapping has typically been studied in *ambiguous naming situations,* in which children hear a novel label in the presence of two or more objects (motivated by the fact that ostensive–deictic naming accounts for only a minimal part of all child-directed utterances; e.g. Snow, 1977). Children as young as 18 months have been found to reliably associate a novel label with a novel referent, when this is presented among one or more familiar objects (e.g. Golinkoff, Hirsh-Pasek, Bailey, & Wenger, 1992; Halberda, 2003; Heibeck & Markman, 1987; Horst & Samuelson, 2008). This ability to solve ambiguous naming situations may be based on an inclination to treat words as mutually exclusive categorical labels for objects and meanings, so that a novel label must always apply to a previously unlabeled object (the *mutual exclusivity constraint* Markman & Wachtel, 1988; Merriman & Bowman, 1989).

Most studies of this kind also usually test to what extent the novel mappings are learned using an offline two-alternative forced-choice test in which the novel objects are presented together (e.g. Golinkoff et al., 1992; Horst & Samuelson, 2008; Jaswal & Markman, 2003; Wilkinson & Mazzitelli, 2003). Testing follows the mapping phase either immediately (as in, e.g. Bion, Borovsky, & Fernald, 2013), after a short delay (1 min: Spiegel & Halberda, 2011; 5 min: Horst & Samuelson, 2008), or after longer time windows (2 days: Jaswal & Markman, 2003). However, unlike immediate recognition—for which the evidence is quite robust—evidence of retention in a successive test phase is not unequivocal, independently of when the test phase takes place (cf. Horst & Samuelson, 2008; Spiegel & Halberda, 2011). This is especially true of mappings that are presented ambiguously (see, e.g. Horst, Scott, & Pollard, 2010). Conversely, ostensive presentation of novel label–object mappings—that is, when the novel label is pronounced in the presence of one novel object alone—generally leads to better performance in the test phase (e.g. Horst & Samuelson, 2008; Mervis & Bertrand, 1994; Woodward, Markman, & Fitzsimmons, 1994).

It is important to note that other approaches have been adopted in the study of word learning (e.g., cross-situational learning; Smith, Smith, & Blythe, 2011; Yu & Smith, 2007) and that some evidence has even challenged the idea that real-world naming situations are particularly ambiguous (e.g. Yu & Smith, 2012). In the current study, we based our experimental procedure on Bion et al. (2013)—although with some important differences, as discussed below. To the best of our knowledge, this is the only previous study to investigate the learning of novel label–object mappings using the LWL procedure. Bion et al. (2013) used LWL with offline frame-by-frame coding to investigate English-learning children's ability to establish and learn two novel label–object associations in situations of either ostensive naming (in which only one novel object was present on the screen during labeling) or ambiguous naming (in which the novel object was presented together with a familiar object during labeling). Their results showed that the children were able to successfully establish the novel mappings from 18 months of age in ostensive naming situations. However, 18-month-olds were not able to establish ambiguously presented mappings; only at 24 months of age did children look at the correct referent after hearing a novel label (see also Golinkoff et al., 1992; Halberda, 2003; Heibeck & Markman, 1987; Horst & Samuelson, 2008). Moreover, when the mappings were presented ostensively, children from 18 months of age showed evidence of retention in a successive test phase, whereas evidence of retention of ambiguously presented mappings was not found until 30 months.

As in Bion et al. (2013), our study consisted of a *teaching phase* and a *test phase* without any delay between the two phases. Through a number of trials in the teaching phase, we familiarized children to two novel label–object mappings (*syf* and *naf;* see "Speech stimuli" section in Method). Throughout the teaching phase, the two labels were presented exclusively either in a "contoid-rich/unreduced" sentence (*Find ____!,* "Find the ____!"), with a clear CVCC structure, or in a "vocoid-rich/reduced" sentence (*Her er ____!,* "Here is the ____!"), with a less clear CVVV structure, in which the last three segments are pronounced as a continuous stretch of vowels without interruptions in voicing. This allowed us to test the impact of phonetic properties of speech on establishing novel mappings. In the subsequent test phase, we assessed to what extent children had learned the mappings and to what extent learning was affected by the phonetic context in which the words were first heard.

The focus of our study was not on investigating the mechanisms behind selecting referents and learning mappings (as in the literature reviewed above) but rather on assessing the effect that a language's sound structure has on these two aspects of word learning. For this reason, we modified the original procedure from Bion et al. (2013) in order to facilitate and maximize learning, which was a prerequisite for testing our hypothesis. Unlike Bion et al., we exposed all children to both ostensive and ambiguous naming situations (in ambiguous naming situations, we used both familiar and unfamiliar objects as distractors; see "Procedure" section in Method). We reasoned that using only ostensive naming in the mapping phase might lead to ceiling effects or to habituation effects (as suggested in part by a pilot version of the current study), thereby failing to detect any potential effect of phonetic structure. At the same time, we reasoned—on the basis of the literature discussed above—that using only ambiguous naming might make the procedure too challenging, thereby potentially hindering learning.

Method

Participants

We tested 41 children in their third year of life (range = 2;0–2;11 [years;months], median = 2;4, 19 girls) from monolingual Danish-speaking families, recruited from the Odense Child Cohort (Kyhl et al., 2015) in the Odense area of Denmark. To be included in the final analyses, each child needed to contribute at least 75% of usable gaze data in each individual trial (i.e., the amount of missing data points due to, for instance, the child looking off-screen was not allowed to exceed 25% of all the possible data points in that trial). One child was excluded for not meeting this requirement. Data from 4 other children were not included in the analyses due to not completing the procedure ($n = 1$), bilingualism ($n = 1$), or technical errors ($n = 2$). Thus, the final sample consisted of 36 children.

Procedure

The procedure comprised a total of 25 trials that were presented over five blocks (as detailed in Fig. 2). Blocks 1 to 4 constituted the teaching phase, whereas Block 5 constituted the test phase. In the teaching phase, the first block consisted of three *Practice trials,* which were intended to familiarize the children with the procedure through exposure to both familiar objects (real-world referents whose names were known to the children) and unfamiliar objects (real-world referents whose names were *not* known to the children). The second block consisted of four *Ostensive Naming trials,* in which two novel object–label pairings (*syf* and *naf;* see next section) were presented individually on the screen, with each of the two novel pairings serving as target twice. The third and fourth blocks consisted of four *Ambiguous (Novel–Familiar) naming trials* and four *Ambiguous (Novel–Unfamiliar) naming trials,* respectively. Here, the two novel pairings *syf* and *naf* were presented together with another object—this was always a familiar object in Ambiguous (Novel–Familiar) trials and an unfamiliar one in Ambiguous (Novel–Unfamiliar) trials—with each novel pairing serving as the target object in half of the trials. By the end of the teaching phase, the children had been exposed six times to each of the two novel pairings (vs four times in Bion et al., 2013). The fifth block constituted our test phase and comprised four *Test trials,* in which *syf* and *naf* were presented side by side on the screen, with each serving as the target object twice. Two *Familiar trials*—in which a number of familiar objects served as both target and distractor—were presented after each block (between Ostensive naming trials and Test trials, for a total of six Familiar trials) to maintain the children's attention (cf. Bion et al., 2013). The entire procedure is reported in detail in the Appendix.

Our procedure differed from that of Bion et al. (2013) in two main ways. First, the children in the original procedure were trained either on eight ostensive naming trials or on eight ambiguous naming trials. Conversely, all our children were trained on both types of naming trials in order to maximize learning (as anticipated in "Using eye-tracking to study word learning" section in Introduction). Sec-

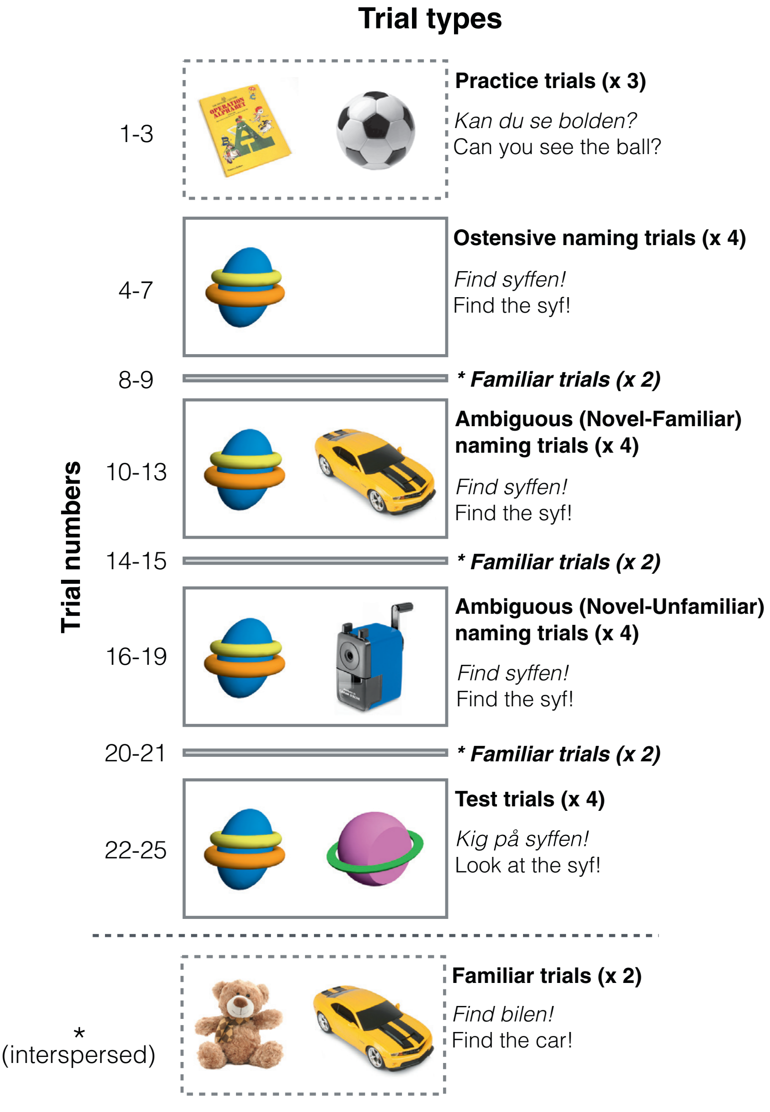

Fig. 2. Overview of the different trial types.

ond, our procedure differed from the original one because of the addition of Ambiguous (Novel–Unfamiliar) trials. The inclusion of these trials was meant to help us test our hypothesis about the role of the Danish sound structure in learning. We reasoned that although Test trials would show whether the children can apply the newly established mappings in the test phase, they alone would not necessarily reveal whether both words had been learned or rather just one word. This is because the children, on naming, might identify the correct target simply by disambiguating the distractor; that is, they might respond correctly to the sentence "Find the syf!" not because they learned the label *syf* but rather because they learned the label for the distractor object *naf.* Therefore, to avoid spurious interpretations of our results in the test phase, we concluded that the addition of Ambiguous (Novel–Unfamiliar) naming trials would provide us with extra information needed to determine to what extent each word had been learned (e.g., the children would look to *syf* in the presence of an unfamiliar object only if the label *syf* was learned).

Each trial began with a 500-ms fixation screen, that is, a picture of a toy positioned in the center. After fixation, a pair of pictures was presented on-screen (although only one picture was presented on Ostensive naming trials), and the carrier phrase followed after 2 s. Exact length (ms) for each carrier phrase and timestamps for target word onsets are reported in Table 1 (the timing was approximately the same for trials in both the teaching and test phases). Each trial lasted approximately 5 s.

Speech stimuli

All carrier phrases and target words are reported in Table 1. As novel words, we used the two monosyllabic nonsense words *syf* ([syf]) and *naf* ([nɑf]). Both novel words are phonotactically legal in Danish but have no obvious phonological neighbors in child-directed speech (cf Højen & Nazzi, 2016). As familiar words, we used four Danish nouns (*baby* [baby], *bog* [book], *bold* [ball], and *kat* [cat]) chosen from vocabulary norms for Danish (Bleses, Vach, Wehberg, Faber, & Madsen, 2007) in the CLEX database (Jørgensen, Dale, Bleses, & Fenson, 2010). All four words were known to all children, according to a checklist completed by the parents at the end of the session. All novel and familiar target words appeared in definite form in the stimulus sentences. For the two novel words, we used the forms *syffen* ([ˈsyfn̩]) and *naffen* ([ˈnɑfn̩]), which result by adding the postponed definite article *-en* plus doubling the final consonant of the root (which is the norm in Danish Allan, Holmes, & Lundskær-Nielsen, 2000).

To assess the impact of phonetic structure on word learning, we embedded the two novel words in two carrier phrases with different phonetic properties: (a) a "contoid rich/unreduced" carrier phrase, *Find ____ [-en]!* ([ˈfe̞nˀ], "Find the ____ !"), with several contoids and a relatively unreduced phonetic structure (CVCC); (b) a "vocoid rich/reduced" carrier phrase (*Her er ____ [-en]!*, [ˈheʌ̯ æ], "Here's the

Table 1
Summary of speech stimuli.

Trial type	Carrier phrase/target word	English translation	Phonetic realization[a]	Duration (ms)	Target word onset (ms)[b]
Ostensive and Ambiguous naming trials	<u>Contoid rich/unreduced:</u>				
	—Find <u>syf</u>fen!	Find the syf!	[ˈfe̞nˀ ˈsyfn̩]	749	328
	—Find <u>naf</u>fen!	Find the naf!	[ˈfe̞nˀ ˈnɑfn̩]	753	314
	<u>Vocoid rich/reduced:</u>				
	— Her er <u>syf</u>fen!	Here's the syf!	[ˈheʌ̯ æ ˈsyfn̩]	667	332
	—Her er <u>naf</u>fen!	Here's the naf!	[ˈheʌ̯ æ ˈnɑfn̩]	690	363
Test trials	—Kig på <u>syf</u>fen!	Look at the syf!	[g̊ ʰi g̊ b̥ʰɔ̞ ˈsyfn̩]	822	413
	—Kig på <u>naf</u>fen!	Look at the naf!	[g̊ ʰi g̊ b̥ʰɔ̞ ˈnɑfn̩]	822	511
	—Kan du se <u>syf</u>fen?	Can you see the syf?	[g̊ ʰæ d̥u ˈse̞ːˀ ˈsyfn̩]	1032	632
	—Kan du se <u>naf</u>fen?	Can you see the naf?	[g̊ ʰæ d̥u ˈse̞ːˀ ˈnɑfn̩]	986	641
Familiar trials	—Kan du se <u>baby</u>en?	Can you see the baby?	[g̊ ʰæ d̥u ˈse̞ːˀ ˈb̥eɪ̯ b̥iːˀin̩]	1057	553
	—Kan du se <u>bold</u>en?	Can you see the ball?	[g̊ ʰæ d̥u ˈse̞ːˀ ˈb̥ʌl̞ˀd̥n̩]	885	543
	—Kan du se <u>bog</u>en?	Can you see the book?	[g̊ ʰæ d̥u ˈse̞ːˀ ˈb̥ɔ̞wˀn̩]	954	519
	—Der er <u>kat</u>ten!	There's the cat!	[ˈd̥ɑ ɑ ˈ g̊ ʰa̞d̥n̩]	598	257
Reinforcement sentences	Skal vi se nogle billeder? Kig med! (Shall we look at some pictures? Let's look together!) Kunne du lide billederne? Her kommer flere! (Did you like the pictures? Here are some more!) Det var flot klaret! (Well done!)				

[a] Non-normalized IPA transcription based on Basbøll (2005).
[b] Target word onset computed from the onset of the sentence stimulus.

____ !"), with several vocoids and a more substantially reduced phonetic structure (CVVV). Fig. 3 shows a spectrogram of the two sentences. Each of the two novel words was paired exclusively with one of the two carrier phrases (contoid rich/unreduced vs vocoid rich/reduced) throughout the teaching phase (i.e., in all Ostensive and Ambiguous naming trials). This allowed us to test our hypothesis that a novel word presented in a phonetically opaque sentence would be harder to learn than a word presented in an unreduced sentence. Each child was randomly assigned to one of two experimental groups, across which these carrier phrase–target word pairings were counterbalanced (e.g., *naf* always occurred in the contoid rich/unreduced carrier phrase in the first group and always in the vocoid rich/reduced carrier phrase in the second group). The children in the two groups did not differ statistically in terms of age and vocabulary size. In the test phase (Test trials), we instead used two new, phonetically similar, and unreduced carrier phrases for both target words, namely *Kig på ____ [-en]!,* "Look at the ____!" and *Kan du se ____ [-en]?,* "Can you see the ____?" This was done to avoid any potential additional effect of phonetic opacity in the test phase. One of four attention-getting sentences (e.g., *Kig på den!,* "Look at it!") followed target offset after a 800-ms pause in all carrier phrases.

Three infant-directed reinforcement sentences were presented at the beginning (*Skal vi se nogle billeder? Kig med!,* "Shall we look at some pictures? Let's look together!"), in the middle (*Kunne du lide billederne? Her kommer flere!,* "Did you like the pictures? Here are some more!"), and at the end of the procedure (*Det var flot klaret!,* "Well done!"), accompanied by colorful drawings of cartoon characters. All speech stimuli were recorded by a young female native speaker of Danish in child-directed form and normalized in Praat (Boersma & Weenink, 2016).

Visual stimuli

Following Bion et al. (2013), we used two computer-generated abstract objects as referents for the novel words, *syf* and *naf* (Fig. 4). The two objects differed considerably in shape and color. Besides the two novel objects, we used four pictures of familiar objects (a baby, a ball, a book, and a cat) and four pictures of unfamiliar objects (a jack plug adapter, a pencil sharpener, a sax mouthpiece, and a turntable cartridge) as distractor objects in Ambiguous (Novel–Familiar) and Ambiguous (Novel–Unfamiliar) naming trials, respectively. In Practice and Familiar trials, the children were presented with mixed pairs of novel, familiar, and unfamiliar objects (baby, ball, book, cat, cow, yo-yo, *syf,* and *naf*). All pictures (novel, familiar, and unfamiliar objects) measured 800×800 pixels and were presented against a white background. Screen location (left-hand vs right-hand side) was quasi-randomized across participants, with each child being randomly allocated to one of four possible sequences in each group (the eight sequences are reported in the Appendix).

Data collection and analysis

Data were collected in an eye-tracking experiment based on the LWL procedure (Fernald et al., 2008). Children were tested in a soundproof room using a Tobii X120 eye-tracker and a 50-inch

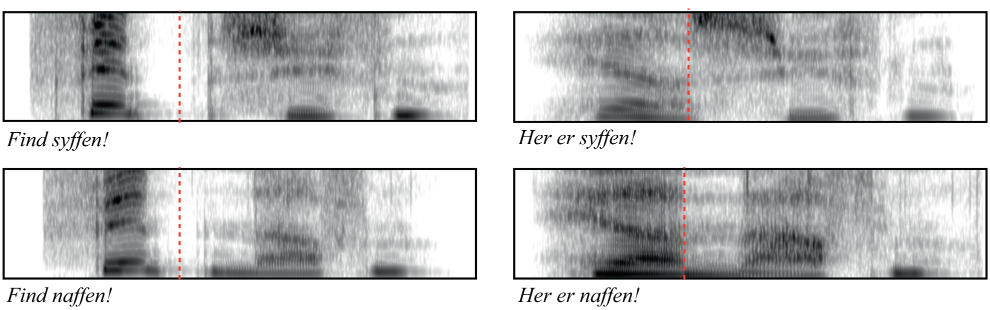

Fig. 3. Spectrograms for the two carrier phrases/target words. The red dotted lines indicate the approximate location of the target word boundaries. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 4. Overview of visual stimuli.

plasma screen. The eye-tracker collected gaze data at a sampling rate of 60 Hz and was calibrated using a 5-point procedure. Each child sat on the parent's lap at approximately 60 cm from the eye-tracker and 140 cm from the screen. The speech stimuli were delivered by two forward-facing loudspeakers positioned below the screen. Parents listened to music and speech through headphones and were instructed not to speak to their children or to interfere with the procedure.

The main analyses were run in R (R Core Team, 2015) using the *eyetrackingR* package (Dink & Ferguson, 2015). Two 800 × 800-pixel areas of interest (AOIs) circumscribed the pictures on the screen. Non-AOI looks were not included in the analysis. Proportional looking data (= time spent looking at target/time spent looking at both target and distractor) served as our dependent measure (arcsine-transformed data produced similar results). For consistency with a previous LWL study (Trecca et al., in preparation), we focused our analysis on a 1500-ms time window starting at 300 ms from target onset (this allows for the time needed to program a saccade; e.g. Fernald & Marchman, 2012; Fernald et al., 2013). For each child, data from 22 trials (4 Ostensive naming trials, 8 Ambiguous naming trials, 4 Test trials, and 6 Familiar trials) were included in the final analyses. However, because only the target object was present on the screen in Ostensive naming trials, these gaze data were uninformative and, therefore, are not discussed in Results.

Gaze data were correlated with productive vocabulary scores from CDI parent reports (the Danish adaptation of the MacArthur–Bates Communicative Development Inventories; Bleses et al., 2008a), which were collected regularly from our participants as part of the longitudinal cohort study mentioned in the "Participants" section above. For the correlation analyses, we used the last parental report available from each child, which was collected on average 2.3 months before testing (SD = 2.01).

Results

Ambiguous naming trials

In Ambiguous (Novel–Familiar) naming trials, the two novel target objects (*syf* and *naf*) were paired with four familiar distractors (baby, ball, book, and cat). Average looking times and mean proportional looks to target word across the time window are reported in Fig. 5. Average looking times to target were significantly below chance (M = .28), $t(56) = -7.26$, $p < .001$); on hearing the novel word, children looked to the novel object 28% of the time. To test how children responded to the different stimuli, we fit a linear mixed-effects model using the *lmer* function from the *lme4* package in R (Bates, Maechler, Bolker, & Walker, 2015), with novel word (*syf* vs *naf*) and experimental group (A vs B) as fixed-effects

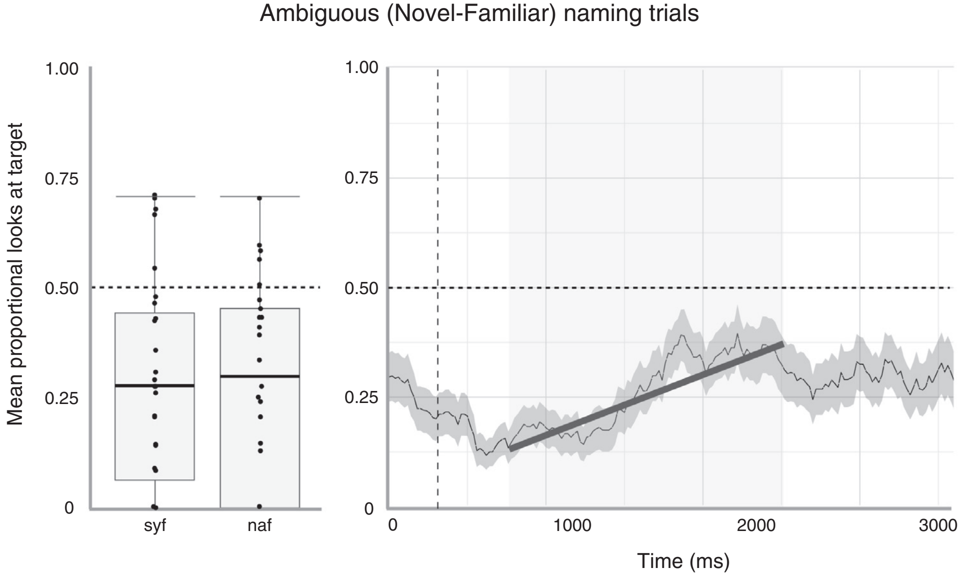

Fig. 5. Left: Mean average looking times in Ambiguous (Novel–Familiar) naming trials. The black line indicates median value, dots indicate individual data points, the gray box indicates interquartile range, and whiskers indicate minimum and maximum values. Right: Time course of looking patterns with superimposed GCA curve (linear time term). The vertical dotted line indicates target onset, the gray square indicates the 1500-ms window over which the analyses were run, and the shaded area around the curve indicates the standard error of the mean.

terms and subject and trial number as a random effect. The model revealed that the children's performance was not significantly different on the two novel words ($\beta = -.01$, $p = .13$) or across the two experimental groups ($\beta = -.02$, $p = .76$). Interaction between the two predictors was also not significant ($\beta = -.02$, $p = .10$).

Gaze patterns throughout the average trial reveal that the children shifted away from the distractor to the correct referent toward the end of each trial. However, looks never reached significance in relation to a chance level of 50%. To quantify the rate at which the children shifted to the target word, we performed a growth curve analysis (GCA; Mirman, Dixon, & Magnuson, 2008). GCAs are typically used in eye-tracking studies to reveal linear trends in how gaze patterns change as a function of time (see Barr, 2008). The analysis involved adding a fixed-effects term for linear time (i.e., first-order orthogonal polynomial term) to the existing predictors in our linear mixed-effects model (we used only linear time terms because the inclusion of quadratic, cubic, and quartic time terms did not improve the fit of the model). Subject and trial numbers were given random intercepts and slopes for the linear time term. Coefficient estimates and significance values for all the terms in the model as well as effect sizes for the model (R^2) are reported in Table 2. We found a positive effect of the linear time term in the model ($\beta = .67$), although this was significant only at $p = .08$. We also found a significant interaction between novel word and linear time ($\beta = -.83$, $p < .001$), indicating an increase in both gaze curves, although more so for *naf* than for *syf* (neither curve reached significance).

Ambiguous (Novel–Unfamiliar) naming trials—in which the distractors were unfamiliar to the children—showed similar patterns (Table 2). Average looking times and mean proportional looks to target word across the time window are reported in Fig. 6. Average looking times to target were significantly below chance ($M = .32$), $t(57) = -4.90$, $p < .001$). A linear mixed-effects model with the same terms as for Ambiguous (Novel–Familiar) naming trials showed no significant difference on the two novel words ($\beta = .01$, $p = 21$) or across the two groups ($\beta = -.05$, $p = .52$). We found a significant interaction between the two predictors ($\beta = -.03$, $p = .02$), with looks to *syf* being higher in Group A (although still

Table 2
Coefficient estimates, significance values, and effect sizes for GCA in Ambiguous naming trials.

	Ambiguous (Novel–Familiar) naming trials				Ambiguous (Novel–Unfamiliar) naming trials			
	Coefficient	*SE*	*t*		Coefficient	*SE*	*t*	
Intercept	0.26	0.04	5.43	***	0.35	0.06	5.24	***
Novel word (syf, naf)	−0.01	0.01	−1.49		0.01	0.01	1.22	
Group (A, B)	−0.02	0.07	−0.29		−0.05	0.09	−0.64	
Linear time	0.67	0.38	1.73	a	0.35	0.41	0.85	
Novel word × Group	−0.02	0.01	−1.62		−0.03	0.01	−2.19	*
Novel Word × Linear Time	−0.83	0.11	−7.36	***	−0.07	0.11	−0.67	
Group × Linear Time	0.05	0.50	0.11		0.16	0.46	0.34	
Novel Word × Group × Linear Time	−0.05	0.16	−0.32		0.06	0.17	0.38	
Effect size (whole model)	$R^2_{marginal} = .037$ $R^2_{conditional} = .335$				$R^2_{marginal} = .015$ $R^2_{conditional} = .409$			

Note. Models specified in R as PropLooks ~ NovelWord * ExpGroup * Time^1 + (1 + Time^1|Subject) + (1 + Time^1 | TrialNumber).
[a] $p < 1$.
* $p < .05$.
*** $p < .001$.

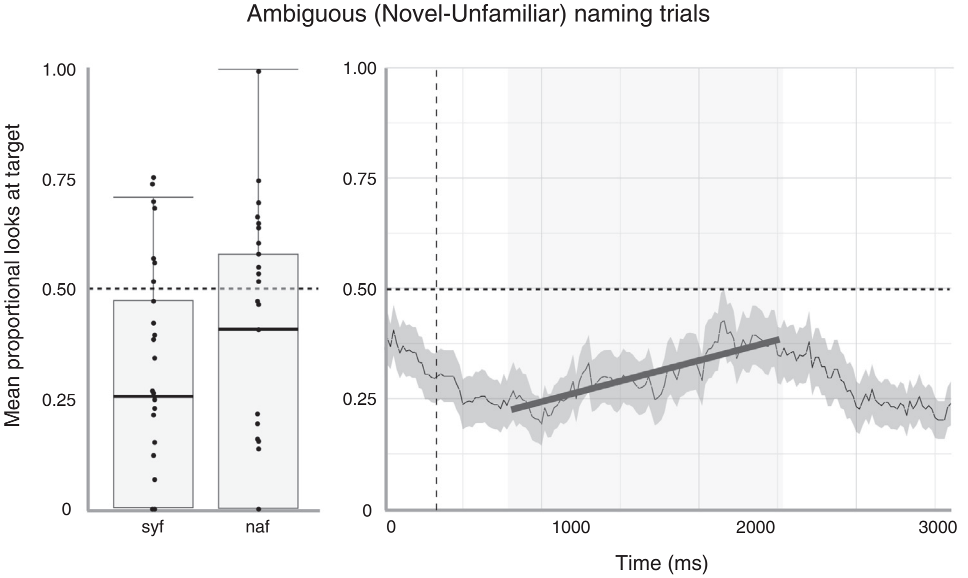

Fig. 6. Left: Mean average looking times in Ambiguous (Novel–Unfamiliar) naming trials. The black line indicates median value, dots indicate individual data points, the gray box indicates interquartile range, and whiskers indicate minimum and maximum values. Right: Time course of looking patterns with superimposed GCA curve (linear time term). The vertical dotted line indicates target onset, the gray square indicates the 1500-ms window over which the analyses were run, and the shaded area around the curve indicates the standard error of the mean.

not above chance level). Gaze shifts from distractor to target as a function of linear time were also positive in this condition, although not statistically significant ($\beta = .35$, $p = .40$).

Results from Ambiguous naming trials showed that Danish-learning children did not attend to the novel referent on hearing a novel word. Rather, they tended to orient to the distractor both when this consisted of familiar objects and when it consisted of unfamiliar objects. Possible reasons for this finding are considered in the Discussion.

Test trials

Next, we looked at how the children performed in Test trials. Average looking times collapsed across the time window (Fig. 7) were not significantly different from chance level ($M = .53$), $t(40) = 0.70$, $p < .48$). We fit a linear mixed-effects model equivalent to the ones described in the previous section, including the linear time term for the GCA. Using maximum likelihood t tests, we found the effect of all predictors and their interactions to be significant at $p < .05$, with the exception of the linear time term ($\beta = .92$, $p = .12$). These significant results are due to differences in looks at the two novel words (with more looks at *syf:* $\beta = .14$, $p < .001$), across the two groups (with more looks at target in Group B: $\beta = .22$, $p < .05$), and the interaction of the two factors, both on average across the time window ($\beta = -.24$, $p < .001$) and as a function of linear time over the course of a trial ($\beta = 3.19$, $p < .001$). To get a more conservative estimate of the effect of each predictor, we computed p values based on a single term deletion test using – 2 log-likelihood ratio tests. This test confirmed a significant effect of the interaction between novel word and group, $\chi^2(1) = 61.02$, $p < .001$, and of the two predictors across time, $\chi^2(1) = 117.38$, $p < .001$. No main effect of the two predictors was confirmed by the single term deletion test. Coefficient estimates and significance values for all the terms in the model as well as effect sizes are reported in Table 3. These results suggest that looks at the novel target named in the contoid rich/unreduced carrier phrase (*naf* in Group A and *syf* in Group B) tended to increase across the 1500-ms time window (Fig. 8). Looks at novel target named in vocoid rich/reduced sentences (*syf* in Group A and *naf* in Group B) instead showed either decreasing or unvarying gaze patterns across trials.

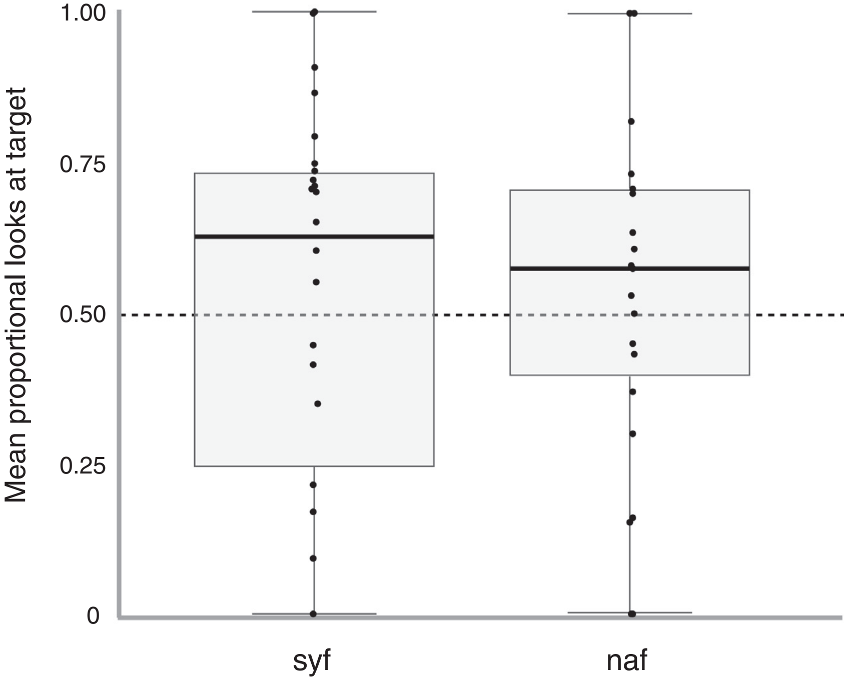

Fig. 7. Mean average looking times in Test trials for the two novel words.

Table 3
Coefficient estimates, significance values, and effect size for GCA in Test trials.

	Coefficient	*SE*	*t* Value	χ^2	
Intercept	0.42	0.07	5.34	–	
Novel word (syf, naf)	0.14	0.01	7.32	0.00	
Group (A, B)	0.22	0.10	2.11	0.93	
Linear time	0.92	0.59	1.56	0.80	
Novel Word × Group	−0.24	0.03	−7.89	61.02	***
Novel Word × Linear Time	−0.79	0.18	−4.21	0.00	
Group × Linear Time	−2.22	0.81	−2.71	0.59	
Novel Word × Group × Linear Time	3.19	0.28	11.18	117.38	***
Effect size (whole model)	$R^2_{\text{marginal}} = .053$ $R^2_{\text{conditional}} = .458$				

Note. Model specified in R as PropLooks ~ NovelWord * ExpGroup * Time^1 + (1 + Time^1|Subject) + (1 + Time^1|TrialNumber).
*** $p < .001$.

Correlation analysis

We then looked at how the children's performance in the training and test phases correlated with (a) their age and (b) their vocabulary size at the age of the last available CDI report before participating in the experiment ($M = 2.3$ months, $SD = 2.01$). Given the difference in timing between the last CDI data collection and the children's participation in the experiment, these results can be viewed only as suggestive. Performance on Ambiguous (Novel–Familiar) naming trials correlated significantly with productive vocabulary ($r = .55$, $p = .01$), but not with age ($r = .27$, $p = .13$); children who had a larger vocabulary at the age of the last available CDI administration were significantly more accurate in disambiguating novel naming situations. This correlation between the children's performance on the behavioral task and their raw CDI scores was confirmed when correlating their performance with their percentile ranking ($r = .49$, $p = .03$) as derived from a norming study of Danish CDI (Bleses et al., 2008a). In Ambiguous (Novel–Unfamiliar) naming trials, we also found a significant correlation between accuracy and vocabulary size ($r = .44$, $p = .05$), but not between accuracy and age ($r = .18$, $p = .31$). However, here the correlation between accuracy and vocabulary size was not confirmed when correlating performance with percentile ranking ($r = .11$, $p = .70$).

In general, children with a larger productive vocabulary were significantly more accurate in mapping novel labels to unknown referents both when the distractors consisted of familiar objects and when they consisted of unfamiliar objects. These results are summarized in Fig. 9. Age ($r = .05$, $p = .74$) and vocabulary size ($r = .14$, $p = .54$) did not correlate with accuracy in Familiar trials. Lastly, we found no significant correlation between accuracy and either age or vocabulary size in Test trials. We also looked at correlations between performance on different trial types; accuracy on Ambiguous (Novel–Familiar) naming trials showed a highly significant correlation with performance on Ambiguous (Novel–Unfamiliar) naming trials ($r = .49$, $p = .005$), possibly due to their similar structure. Ambiguous (Novel–Familiar) naming trials also correlated with performance on Familiar trials ($r = .39$, $p = .02$), but not with that on Test trials ($r = .20$, $p = .32$). No other significant correlations were found between the remaining conditions. The complete results are reported in Table 4.

Familiar words

In addition, we looked at the children's gaze patterns in relation to the familiar objects used as targets in Familiar trials (Fig. 10). Accuracy in referent identification was high on all four target words. Average looking times for *bog* ("book") and *bold* ("ball") were 75% and 66%, respectively, both significantly different from chance, $t(25) = 6.51$, $p < .001$, and $t(30) = 3.67$, $p < .001$, respectively. Proportional gaze patterns in relation to both words unfolded as expected; they started at chance level at trial onset and increased to a mean of about 80% proportional looks to target at around 800 ms from its onset. Looks at *bog* remained at a level of about 80% throughout the trial, whereas looks at *bold*

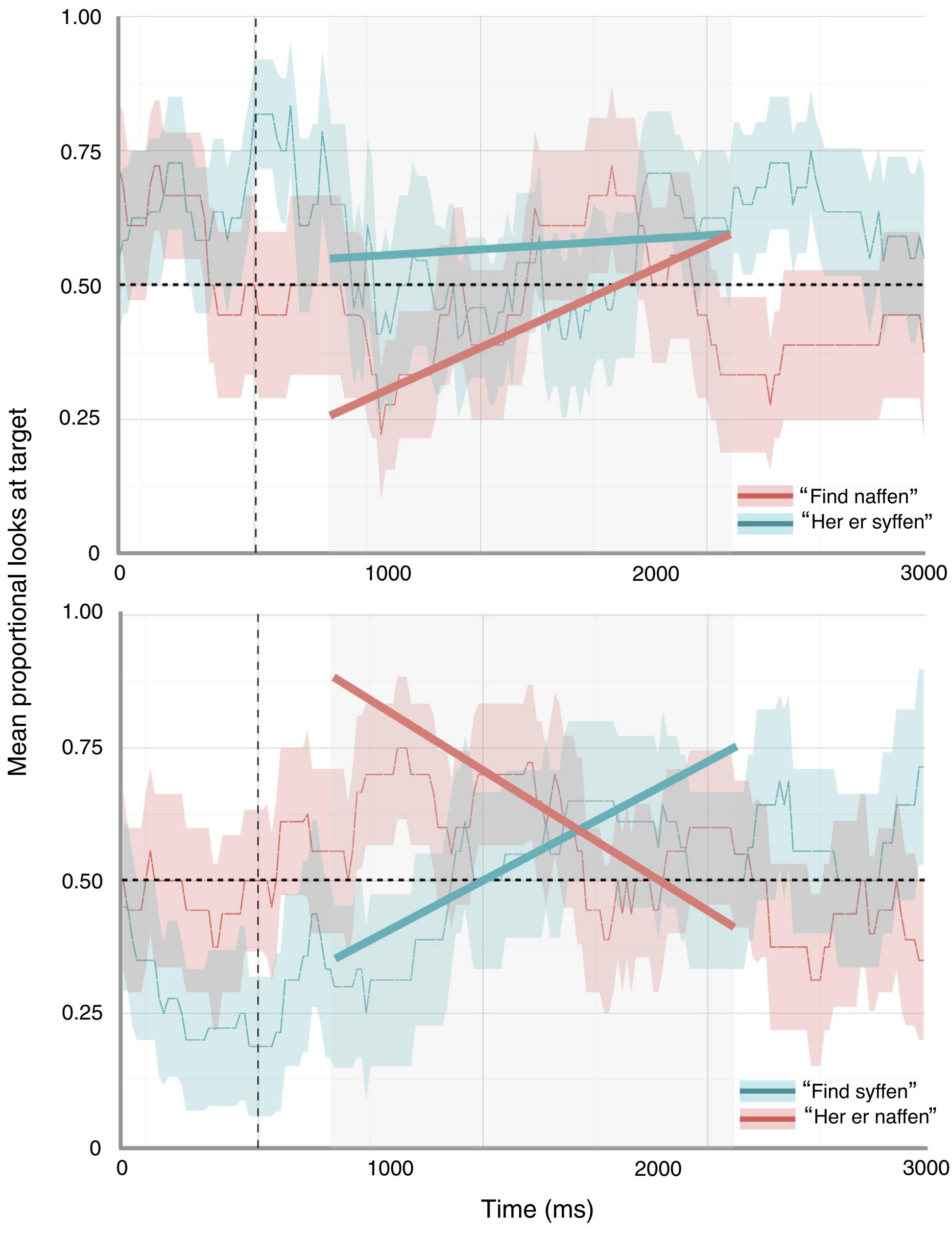

Fig. 8. Gaze patterns for Group A (top) and Group B (bottom) in Test trials, with superimposed growth curves (linear time). The vertical dotted line indicates target onset, the gray square indicates the 1500-ms window over which the analyses were run, and the shaded area around the curve indicates the standard error of the mean.

plummeted to chance level at trial offset. A different pattern was found for *baby* (“baby”) and *kat* (“cat”). Children oriented at *baby* consistently throughout the time window on 91% of trials on average (significantly different from chance, $t(31) = 19.50$, $p < .001$). This is consistent with evidence suggest-

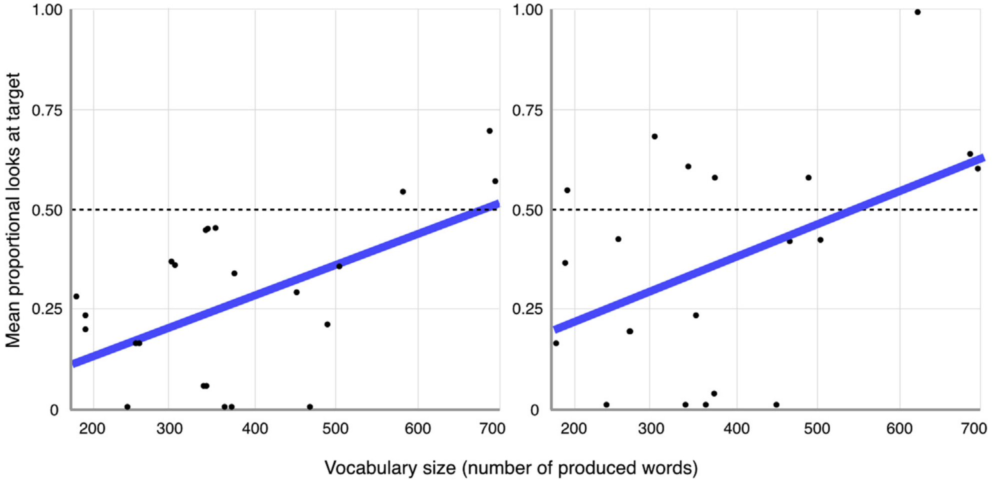

Fig. 9. Significant correlations between size of productive vocabulary and performance on Ambiguous (Novel–Familiar) naming trials (left) and Ambiguous (Novel–Unfamiliar) naming trials (right).

Table 4
Correlation matrix for age, vocabulary size, and trial types.

	1	2	3	4	5	6
1. Age	1.00	.00	.27	.05	.18	.19
2. Vocabulary size		1.00	.55**	.14	.44*	.17
3. Ambiguous (Novel–Familiar) naming trials			1.00	.39*	.49***	.20
4. Familiar trials				1.00	.15	.06
5. Ambiguous (Novel–Unfamiliar) naming trials					1.00	.00
6. Test trials						1.00

* $p < .05$.
** $p < .01$.
*** $p < .001$.

ing that pictures of animate agents elicit more attention in young children (Childers & Echols, 2004). Looks to *kat* were also high at trial onset (~80%) but plummeted dramatically to around 25% mid-trial. Reorientation to the correct picture occurred only toward the end of the 1500-ms time window. On average across the time window, children looked at *kat* 53% of the time, which was not significantly different from chance level, $t(27) = 0.59$, $p = .55$. The reason is possibly that, of the four familiar words, *kat* was the only one to be presented in a vocoid rich/reduced (CVVV) carrier phrase. We suggest that children oriented at the target picture at trial onset due to a natural preference for animate agents but looked away while processing the speech stimulus because of the uncertainty brought about by the vocoid rich/reduced carrier phrase.

Discussion

The aim of this study was to investigate the establishment of novel label–object mappings in a group of children learning Danish, a relatively understudied language characterized by unusual phonetic/phonological properties. Danish has a more opaque sound structure than other closely related languages (e.g., Norwegian and Swedish; Basbøll, 2005; Grønnum, 2003), which is believed to make

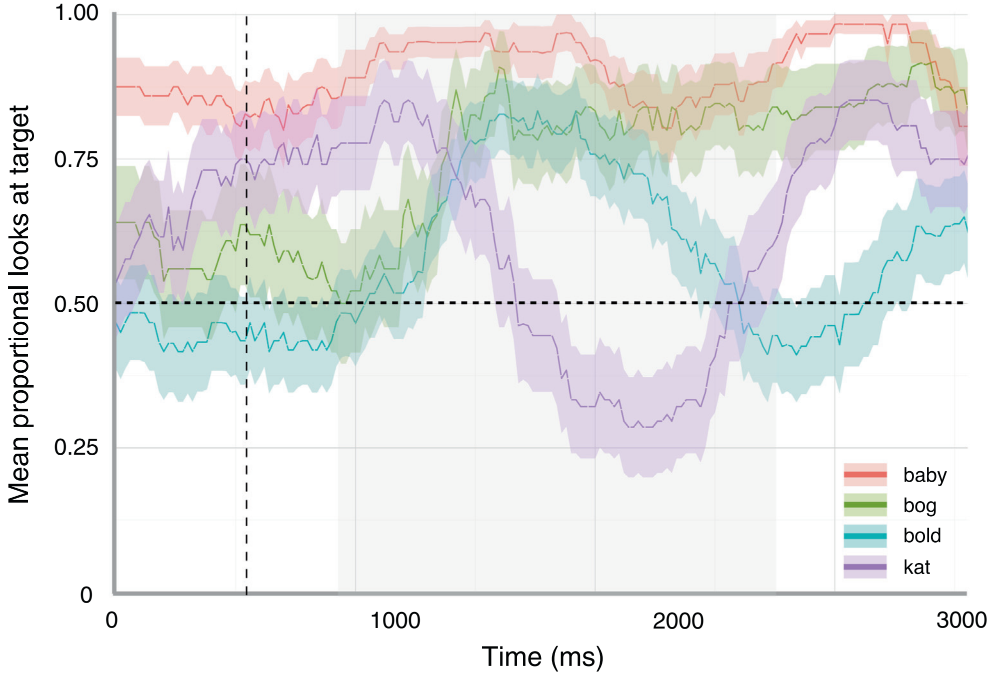

Fig. 10. Gaze patterns in Familiar trials. The vertical dotted line indicates target onset, the gray square indicates the 1500-ms window over which the analyses were run, and the shaded area around the curve indicates the standard error of the mean.

syllable and word boundaries in the speech stream less discernible for young learners (Bleses & Basbøll, 2004). The opacity of Danish speech has been suggested to account for evidence showing that Danish-learning toddlers lag behind in the acquisition of both vocabulary and morphology (Bleses, Basbøll, Lum et al., 2011; Bleses, Basbøll and Vach, 2011; Bleses et al., 2008b). The phonological processes that make Danish speech less transparent (above all, the pervasive weakening of consonants to semivowels) have recently been shown to affect online language processing in an eye-tracking experiment with 2-year-old children (Trecca et al., in preparation). In the study, children's recognition of known words was found to be less accurate when these words occurred in sentences with a higher degree of phonetic reduction. Given that the ability to rapidly process the incoming language input is a precondition for language learning (Christiansen & Chater, 2016), and that performance in online language processing predicts lexical development rates (Fernald & Marchman, 2012), in this study we investigated whether the structural idiosyncrasies of Danish speech likewise can affect how children learn novel words. We found two major results in our study, which are discussed in turn.

Danish-learning toddlers perform poorly in ambiguous referent selection tasks

Our results showed that Danish-learning children at 24–35 months of age were not able as a group to select the correct referent in both types of Ambiguous naming trials. An analysis of how gaze patterns unfolded throughout the time window showed that the children started out by looking at the familiar object and then progressively shifted to the target object over time, although without reaching above a chance level of 50%. This was in contrast to our expectation, based on studies of English-learning children using a similar trial structure, that the children would be able to solve ambiguous naming situations. For instance, an eye-tracking study by Bion et al. (2013) showed evidence of correct referent selection in children from 2 years of age in eight 6-s trials, in which a novel object was paired with a familiar object, with the novel object serving as target (see also Carey and Bartlett (1978), Golinkoff et al. (1992), Heibeck and Markman (1987), and Horst and Samuelson (2008), for similar results in preferential looking/pointing studies).

The fact that the children in our experiment started by orienting to the familiar object after having heard the novel label has been previously observed in the literature: In an eye-tracking study of English-speaking children and adults Halberda (2006), found that correct referent selection in ambiguous naming tasks was always preceded by the identification and rejection of the familiar referent. That is, on hearing a novel word, children and adults consistently either oriented or maintained fixation to the familiar object before orienting to the novel object. This suggests that the process of mapping is based on three steps. First, listeners orient to the familiar object and retrieve its label from memory. Second, if the retrieved label does not match the auditory stimulus, the familiar object is ruled out as possible referent. Third, the correct referent is consequently selected (Halberda, 2003, 2006). Therefore, although we expected our children to start out by looking at the distractor, we did not expect that they would not make the shift to the target object within the time window of a trial. We offer here two possible interpretations of this result, based on our initial hypothesis.

A first possible interpretation is that the identification–rejection process described by Halberda (2006) is impeded by the opaque phonetic structure of Danish. This phenomenon can manifest itself in two ways:

1. Danish-learning children may need longer time to process the speech stimulus (as suggested by, e.g. Trecca et al., in preparation), which gives the children less time to correctly identify and reject the familiar object within the duration of a trial (cf. Horst et al., 2010).
2. Danish-learning children may need longer time to reject the familiar object as possible referent even after having correctly processed the speech stimulus. This may be the case if phonological representations of vocabulary were less robust in speakers of Danish compared with speakers of other languages (as suggested by, e.g. Bleses & Basbøll, 2004; Bleses, Basbøll and Vach, 2011). In this case, matching the auditory information with an internal representation of a word would be more costly in terms of time and cognitive effort, thereby resulting in the observed delay.

If either variation of this interpretation is correct, we can speculate that the children's looking patterns could have exceeded chance level if children had been given more time to solve the task. Gaze switches from distractors to novel targets increased throughout the 1500-ms time window as a function of time, and when extending our analyses to the entire time span of our recorded data (2400 ms starting at 300 ms from target onset), we still found a significant progressive shift toward target as a function of linear time ($\beta = -9.09$, $p < .001$), suggesting that the use of an even longer time window in future studies may be necessary to address this issue (a similar point was made in Bion et al., 2013, p. 43).

A second possible interpretation of the results is that Danish-learning toddlers may lag behind in the onset of ambiguous referent selection skills (*disambiguation skills* in Bion et al., 2013), such as the *mutual exclusivity constraint* (Markman & Wachtel, 1988), which are well documented in English-learning children as young as 18 months (Halberda, 2003). Previous research has shown that vocabulary size correlates significantly with referent selection skills in typically developing children (e.g. Mervis & Bertrand, 1994; Torkildsen et al., 2008; Woodward et al., 1994; but see Tan & Schafer, 2005), suggesting that mechanisms such as mutual exclusivity emerge only when children have learned a sufficient number of words (e.g. Graham, Poulin-Dubois, & Baker, 1998; Houston-Price, Caloghiris, & Raviglione, 2010). This interpretation is supported by evidence showing that typically developing children show a faster onset of these referent selection skills than both late talkers (Weismar, Venker, Evans, & Moyle, 2013) and children with specific language impairment (Jackson, Leitao, & Claessen, 2016). Knowing a considerable number of words is intuitively advantageous in the process of identifying and rejecting familiar objects as possible referents for novel labels. Note that the children's general vocabulary proficiency, rather than knowledge of the particular words in the referent selection task, seems to be of the essence (Kalashnikova, Mattock, & Monaghan, 2016). Consistent with this evidence, we found the children's performance on Ambiguous (Novel–Familiar) naming trials to be significantly correlated with the size of their productive vocabulary, but not with age. This suggests that the ability to disambiguate naming situations is likely to develop as a result of reaching specific linguistic milestones rather than as a function of general cognitive maturation (as also found in Bion et al., 2013; Graham et al., 1998). This interpretation of our results suggests that, in the same way as late talkers constitute the lower end of a normal distribution in the development of mapping skills, Danish-learning children as a group may constitute the lower end of a *cross-linguistic distribution.*

Lastly, we considered the possibility that our results may be driven by aspects of our procedure, in particular by a visual novelty bias; by the time the children were presented with the two novel objects in Ambiguous (Novel–Familiar) naming trials, they had already been exposed twice to each novel object in Ostensive naming trials, possibly making the novel objects less appealing in the ambiguous mapping process. As a consequence, children may have maintained fixation to the distractors in Ambiguous naming trials longer because of their visual novelty (novelty effects in referent selection have been observed before Horst, Samuelson, Kucker, & McMurray, 2011). At the same time, we see no substantial differences in looking patterns between Ambiguous (Novel–Familiar) and Ambiguous (Novel–Unfamiliar) naming trials despite the fact that the objects in the latter type of trials were entirely novel (by the time the children were presented with the unfamiliar distractors in Trials 16–19, they had already seen the familiar distractors a number of times in both Practice and Familiar trials). Still, we acknowledge the potential bias that this aspect of the procedure may bring to our results.

Phonetic properties of the speech stimuli may affect the acquisition of novel object–label mappings

Our results showed that the children as a group were not able to learn the two novel object–label mappings (given the specific amount of exposure they received in the procedure), which is consistent with the children's poor performance on Ambiguous naming trials. This result contrasts with what Bion et al. (2013) observed in English-learning children at 18–30 months of age who received a similar amount of exposure to novel mappings.

However, despite the poor performance as a group, growth curve analyses of changes in our children's gaze patterns across the time window revealed an effect of the phonetic structure of the speech stimuli on the acquisition of the novel labels. Specifically, we found that the children, throughout each trial, tended to look increasingly more at objects whose names were presented in the contoid rich/unreduced carrier phrase ("*Find syffen/naffen!*") during the original teaching phase in both experimental groups. At the same time, looks at objects whose labels were originally presented in the vocoid rich/reduced carrier phrase ("*Her er syffen/naffen!*") either remained at chance level or decreased throughout the trial. This result is in line with our initial hypothesis that accuracy in establishing novel label–object pairings may be affected by the phonetic properties of the Danish speech stimuli. Assuming that language processing happens incrementally (e.g. Monaghan & Christiansen, 2010), the challenging nature of vocoid rich/reduced (vs contoid rich/unreduced) sentences may impede processing of the input and thereby impede learning. This is predicted by the hypothesized impact of the *Now-or-Never Bottleneck* on language processing (Christiansen & Chater, 2016); the incoming linguistic input must be processed as fast and as accurately as possible before it is subject to interference from new incoming information.

Although this result is mostly driven by the performance of the children who did learn the mappings, we interpret it as indicating that an effect of phonetic opacity on word learning is to be expected in situations where learning has taken place. Notice also that evidence of learning following accurate mapping is not unequivocal in the literature (see "Using eye-tracking to study word learning" section in Introduction), suggesting that the two processes should not be conflated. More surprising is the fact that Ostensive naming trials did not seem to contribute to word learning. Novel mappings presented in ostensive naming scenarios are typically learned accurately even after short exposure periods (see "Using eye-tracking to study word learning" section) and after as little as *one* single exposure (Spiegel & Halberda, 2011). This result may provide further support for the idea that Danish-learning children may in general need more exposure to novel label–object mappings even when these are presented ostensively. Further research is needed to investigate this possibility.

Lastly, our results suggest that phonetic opacity in carrier phrases may have impeded the identification of known referents in Familiar trials when these occurred in a vocoid rich/reduced phrase. This finding corroborates the results of a previous study (Trecca et al., submitted for publication) with (a) a different set of target words, speech stimuli, and visual stimuli and (b) a different sample of children up to 1 year older than those in the original experiment. The latter suggests that the impact of phonetic opacity on processing may be stronger than initially thought and may continue into late toddlerhood. Still, we urge caution with this interpretation of the results because the Familiar trials were not counterbalanced (they were intended as filler trials in this procedure; see "Procedure" section in Method).

Conclusion

Danish may be a particularly hard language to learn. Recent experimental data have shown that the complex phonetic structure of Danish may impede online language processing, and researchers have argued that this may account for the slower lexical development observed in Danish-learning children compared with children learning other languages. With this study, we took a first step toward investigating whether the opaque sound structure of Danish affects the acquisition of new words. Our results revealed two critical trends. First, Danish-learning 2-year-olds performed poorly on mapping novel labels to novel objects. We argued that this finding may be due to the challenges brought on by the Danish speech input and/or to the fact that Danish-learning children follow a slower trajectory in language acquisition, which may impede their acquisition of ambiguous referent selection skills. Second, the data pointed to a possible effect of the phonetic properties of speech on the accuracy with which the novel label–object mappings were acquired, suggesting that an opaque speech signal not only can hinder processing but also can affect novel word learning.

More generally, this study suggests that the combination of causes and effects behind the slow learning rates of Danish may be more complex and multifaceted than originally hypothesized. We propose that the challenges posed by the Danish speech signal to processing may have a direct impact on the very early stages of language acquisition, for example, by hindering the acquisition of the first 50 words (cf. Kalashnikova et al., 2016). This initial delay may have repercussions for the development of word learning skills (such as ambiguous referent selection, which seems to presuppose a certain level of vocabulary proficiency). This, in turn, may lead to a further delay in lexical development that carries on into late toddlerhood. A more definitive interpretation of our results may require a replication of the results in a control language with a less opaque sound structure while matching children across language groups for either age or vocabulary size. Nonetheless, the current results raise intriguing questions—outside the scope of the current article—about the general learnability and historical evolution of Danish, which may have important implications for the language sciences and which we hope to pursue in future research.

Acknowledgments

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Appendix A. Experimental procedure

Trial nr.	Left pic	Right pic	Target	Trial type	Trial nr.	Left pic	Right pic	Target	Trial type	Trial nr.	Left pic	Right pic	Target	Trial type	Trial nr.	Left pic	Right pic	Target	Trial type
Procedure A1					Procedure A2					Procedure A3					Procedure A4				
1	Baby	–	Left pic	Practice	1	–	Baby	Right pic	Practice	1	Baby	–	Left pic	Practice	1	–	Baby	Right pic	Practice
2	Ball	Cow	Right pic	Practice	2	Cow	Ball	Left pic	Practice	2	Ball	Cow	Right pic	Practice	2	Cow	Ball	Left pic	Practice
3	Yo-yo	Book	Right pic	Practice	3	Book	Yo-yo	Left pic	Practice	3	Yo-yo	Book	Right pic	Practice	3	Book	Yo-yo	Left pic	Practice
4	–	Naf	Right pic	Ostensive	4	Naf	–	Left pic	Ostensive	4	–	Naf	Right pic	Ostensive	4	Naf	–	Left pic	Ostensive
5	Naf	–	Left pic	Ostensive	5	–	Naf	Right pic	Ostensive	5	Naf	–	Left pic	Ostensive	5	–	Naf	Right pic	Ostensive
6	–	Syf	Right pic	Ostensive	6	Syf	–	Left pic	Ostensive	6	–	Syf	Right pic	Ostensive	6	Syf	–	Left pic	Ostensive
7	Syf	–	Left pic	Ostensive	7	–	Syf	Right pic	Ostensive	7	Syf	–	Left pic	Ostensive	7	–	Syf	Right pic	Ostensive
8	Cat	Cow	Left pic	Familiar	8	Cow	Cat	Right pic	Familiar	8	Cat	Cow	Left pic	Familiar	8	Cow	Cat	Right pic	Familiar
9	Naf	Ball	Right pic	Familiar	9	Ball	Naf	Left pic	Familiar	9	Naf	Ball	Right pic	Familiar	9	Ball	Naf	Left pic	Familiar
10	Monkey	Naf	Right pic	Amb (Novel-Fam)	10	Naf	Teddy bear	Left pic	Amb (Novel-Fam)	10	Car	Naf	Right pic	Amb (Novel-Fam)	10	Naf	Duck	Left pic	Amb (Novel-Fam)
11	Naf	Duck	Left pic	Amb (Novel-Fam)	11	Monkey	Naf	Right pic	Amb (Novel-Fam)	11	Naf	Teddy bear	Left pic	Amb (Novel-Fam)	11	Car	Naf	Right pic	Amb (Novel-Fam)
12	Car	Syf	Right pic	Amb (Novel-Fam)	12	Syf	Duck	Left pic	Amb (Novel-Fam)	12	Monkey	Syf	Right pic	Amb (Novel-Fam)	12	Syf	Teddy bear	Left pic	Amb (Novel-Fam)
13	Syf	Teddy bear	Left pic	Amb (Novel-Fam)	13	Car	Syf	Right pic	Amb (Novel-Fam)	13	Syf	Duck	Left pic	Amb (Novel-Fam)	13	Monkey	Syf	Right pic	Amb (Novel-Fam)
14	Baby	Syf	Left pic	Familiar	14	Syf	Baby	Right pic	Familiar	14	Baby	Syf	Left pic	Familiar	14	Syf	Baby	Right pic	Familiar
15	Cow	Ball	Right pic	Familiar	15	Ball	Cow	Left pic	Familiar	15	Cow	Ball	Right pic	Familiar	15	Ball	Cow	Left pic	Familiar
16	Sharpener	Naf	Right pic	Amb (Novel-Unfam)	16	Naf	Cartridge	Left pic	Amb (Novel-Unfam)	16	Mouthpiece	Naf	Right pic	Amb (Novel-Unfam)	16	Naf	JackPlug	Left pic	Amb (Novel-Unfam)
17	Naf	Cartridge	Left pic	Amb (Novel-Unfam)	17	Mouthpiece	Naf	Right pic	Amb (Novel-Unfam)	17	Naf	JackPlug	Left pic	Amb (Novel-Unfam)	17	Sharpener	Naf	Right pic	Amb (Novel-Unfam)
18	Mouthpiece	Syf	Right pic	Amb (Novel-Unfam)	18	Syf	JackPlug	Left pic	Amb (Novel-Unfam)	18	Sharpener	Syf	Right pic	Amb (Novel-Unfam)	18	Syf	Cartridge	Left pic	Amb (Novel-Unfam)
19	Syf	JackPlug	Left pic	Amb (Novel-Unfam)	19	Sharpener	Syf	Right pic	Amb (Novel-Unfam)	19	Syf	Cartridge	Left pic	Amb (Novel-Unfam)	19	Mouthpiece	Syf	Right pic	Amb (Novel-Unfam)
20	Cat	Book	Right pic	Familiar	20	Book	Cat	Left pic	Familiar	20	Cat	Book	Right pic	Familiar	20	Book	Cat	Left pic	Familiar

(*continued on next page*)

Appendix A. (*continued*)

Trial nr.	Left pic	Right pic	Target	Trial type	Trial nr.	Left pic	Right pic	Target	Trial type	Trial nr.	Left pic	Right pic	Target	Trial type	Trial nr.	Left pic	Right pic	Target	Trial type
21	Baby	Ball	Left pic	Familiar	21	Ball	Baby	Right pic	Familiar	21	Baby	Ball	Left pic	Familiar	21	Ball	Baby	Right pic	Familiar
22	Naf	Syf	Left pic	Test	22	Syf	Naf	Right pic	Test	22	Naf	Syf	Left pic	Test	22	Syf	Naf	Right pic	Test
23	Syf	Naf	Right pic	Test	23	Naf	Syf	Left pic	Test	23	Syf	Naf	Right pic	Test	23	Naf	Syf	Left pic	Test
24	Syf	Naf	Left pic	Test	24	Naf	Syf	Right pic	Test	24	Syf	Naf	Left pic	Test	24	Naf	Syf	Right pic	Test
25	Naf	Syf	Right pic	Test	25	Syf	Syf	Left pic	Test	25	Naf	Syf	Right pic	Test	25	Syf	Naf	Left pic	Test
Procedure B1					Procedure B2					Procedure B3					Procedure B4				
1	Baby	–	Left pic	Practice	1	–	Baby	Right pic	Practice	1	Baby	–	Left pic	Practice	1	–	Baby	Right pic	Practice
2	Ball	Cow	Right pic	Practice	2	Cow	Ball	Left pic	Practice	2	Ball	Cow	Right pic	Practice	2	Cow	Ball	Left pic	Practice
3	Yo-yo	Book	Right pic	Practice	3	Book	Yo-yo	Left pic	Practice	3	Yo-yo	Book	Right pic	Practice	3	Book	Yo-yo	Left pic	Practice
4	–	Naf	Right pic	Ostensive	4	Naf	–	Left pic	Ostensive	4	–	Naf	Right pic	Ostensive	4	Naf	–	Left pic	Ostensive
5	Naf	–	Left pic	Ostensive	5	–	Naf	Right pic	Ostensive	5	Naf	–	Left pic	Ostensive	5	–	Naf	Right pic	Ostensive
6	–	Syf	Right pic	Ostensive	6	Syf	–	Left pic	Ostensive	6	–	Syf	Right pic	Ostensive	6	Syf	–	Left pic	Ostensive
7	Syf	–	Left pic	Ostensive	7	–	Syf	Right pic	Ostensive	7	Syf	–	Left pic	Ostensive	7	–	Syf	Right pic	Ostensive
8	Cat	Cow	Left pic	Familiar	8	Cow	Cat	Right pic	Familiar	8	Cat	Cow	Left pic	Familiar	8	Cow	Cat	Right pic	Familiar
9	Naf	Ball	Right pic	Familiar	9	Ball	Naf	Left pic	Familiar	9	Naf	Ball	Right pic	Familiar	9	Ball	Naf	Left pic	Familiar
10	Monkey	Naf	Right pic	Amb (Novel-Fam)	10	Naf	Teddy bear	Left pic	Amb (Novel-Fam)	10	Car	Naf	Right pic	Amb (Novel-Fam)	10	Naf	Duck	Left pic	Amb (Novel-Fam)
11	Naf	Duck	Left pic	Amb (Novel-Fam)	11	Monkey	Naf	Right pic	Amb (Novel-Fam)	11	Naf	Teddy bear	Left pic	Amb (Novel-Fam)	11	Car	Naf	Right pic	Amb (Novel-Fam)
12	Car	Syf	Right pic	Amb (Novel-Fam)	12	Syf	Duck	Left pic	Amb (Novel-Fam)	12	Monkey	Syf	Right pic	Amb (Novel-Fam)	12	Syf	Teddy bear	Left pic	Amb (Novel-Fam)
13	Syf	Teddy bear	Left pic	Amb (Novel-Fam)	13	Car	Syf	Right pic	Amb (Novel-Fam)	13	Syf	Duck	Left pic	Amb (Novel-Fam)	13	Monkey	Syf	Right pic	Amb (Novel-Fam)
14	Baby	Syf	Left pic	Familiar	14	Syf	Baby	Right pic	Familiar	14	Baby	Syf	Left pic	Familiar	14	Syf	Baby	Right pic	Familiar
15	Cow	Ball	Right pic	Familiar	15	Ball	Cow	Left pic	Familiar	15	Cow	Ball	Right pic	Familiar	15	Ball	Cow	Left pic	Familiar
16	Sharpener	Naf	Right pic	Amb (Novel-Unfam)	16	Naf	Cartridge	Left pic	Amb (Novel-Unfam)	16	Mouthpiece	Naf	Right pic	Amb (Novel-Unfam)	16	Naf	JackPlug	Left pic	Amb (Novel-Unfam)
17	Naf	Cartridge	Left pic	Amb (Novel-Unfam)	17	Mouthpiece	Naf	Right pic	Amb (Novel-Unfam)	17	Naf	JackPlug	Left pic	Amb (Novel-Unfam)	17	Sharpener	Naf	Right pic	Amb (Novel-Unfam)
18	Mouthpiece	Syf	Right pic	Amb (Novel-Unfam)	18	Syf	JackPlug	Left pic	Amb (Novel-Unfam)	18	Sharpener	Syf	Right pic	Amb (Novel-Unfam)	18	Syf	Cartridge	Left pic	Amb (Novel-Unfam)

19	Syf	JackPlug	Left pic	Amb (Novel-Unfam)	19	Sharpener	Syf	Right pic	Amb (Novel-Unfam)	19	Syf	Cartridge	Left pic	Amb (Novel-Unfam)	19	Mouthpiece	Syf	Right pic	Amb (Novel-Unfam)
20	Cat	Book	Right pic	Familiar	20	Book	Cat	Left pic	Familiar	20	Cat	Book	Right pic	Familiar	20	Book	Cat	Left pic	Familiar
21	Baby	Ball	Left pic	Familiar	21	Ball	Baby	Right pic	Familiar	21	Baby	Ball	Left pic	Familiar	21	Ball	Baby	Right pic	Familiar
22	Naf	Syf	Left pic	Test	22	Syf	Naf	Right pic	Test	22	Naf	Syf	Left pic	Test	22	Syf	Naf	Right pic	Test
23	Syf	Naf	Right pic	Test	23	Naf	Syf	Left pic	Test	23	Syf	Naf	Right pic	Test	23	Naf	Syf	Left pic	Test
24	Syf	Naf	Left pic	Test	24	Naf	Syf	Right pic	Test	24	Syf	Naf	Left pic	Test	24	Naf	Syf	Right pic	Test
25	Naf	Syf	Right pic	Test	25	Syf	Naf	Left pic	Test	25	Naf	Syf	Right pic	Test	25	Syf	Naf	Left pic	Test

Note. nr., number.

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