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Toddlers' Processing of Phonological Alternations: Early Compensation for Assimilation in English and French

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Using a picture pointing task, this study examines toddlers' processing of phonological alternations that trigger sound changes in connected speech. Three experiments investigate whether 2;5- to 3-year-old children take into account assimilations—processes by which phonological features of one sound spread to adjacent sounds—for the purpose of word recognition (e.g., in English, *ten pounds* can be produced as *te[mp]ounds*). English toddlers (n = 18) show sensitivity to native place assimilations during lexical access in Experiment 1. Likewise, French toddlers (n = 27) compensate for French voicing assimilations in Experiment 2. However, French toddlers (n = 27) do not take into account a hypothetical non-native place assimilation rule in Experiment 3, suggesting that compensation for assimilation is already language specific.

Acquiring the sound system of their native language is not an easy task for young children. Languages differ widely in their phonological structure, not only with respect to the sound categories they employ, but also with respect to variation according to speaker, speech rate, dialect, and linguistic context. Over the last few decades, psycholinguistic research has shown that children begin to attune their perceptual system to native sound categories within the 1st year of life (Best, McRoberts, & Sithole, 1988; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Werker & Lalonde, 1988; Werker & Tees, 1984). Recent studies on early word recognition have found that children are sensitive to native phonological contrasts in words by 12 months of age (Bailey & Plunkett, 2002; Mani, Coleman, & Plunkett, 2008; Mani & Plunkett, 2008, 2010; Swingley & Aslin, 2000, 2002). As for the impact of variation on word recognition, children can accommodate some degree of speaker variability from the first year of life (Houston & Jusczyk, 2000; Schmale & Seidl, 2009), and begin to learn how to cope with dialect variability within the first 2 years (e.g., Best, Tyler, Gooding, Orlando, & Quann, 2009; Schmale, Cristià, Seidl, & Johnson, 2010; Schmale & Seidl, 2009). However, little is known about their processing of context-dependent variation in speech introduced by phonological alternations.

Phonological alternations can alter the surface form of sounds and words when they are juxtaposed in connected speech. In English, for instance, vowels are nasalized when they are followed by a nasal consonant (cf. *pet* [pɛt] and *pen* [pɛ̃n]), and certain consonants can change their place of articulation as a function of the following sound (e.g., *ten* can be realized with a final [m] in the phrase *ten pounds*). For the purposes of word recognition, listeners have to take into account such alternations because they can introduce word form variation; for instance, English listeners must recognize *tem* as a variant of *ten* when they hear *te[mp]ounds*.

Phonological alternations differ across languages and thus have to be learned as part of the language-specific phonological system. This acquisition may

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well start very early in life: Artificial language learning studies show that infants between 7 and 12 months of age are sensitive to the distributional properties of language and can use these properties to learn basic linguistic regularities from short exposure (Chambers, Onishi, & Fisher, 2003; Gomez & Gerken, 1999; Marcus, Vijavan, Rao, & Vishton, 1999; Seidl, Cristià, Onishi, & Bernard, 2009; White, Peperkamp, Kirk, & Morgan, 2008). Although a lot of research has been dedicated to the exploration of nontarget regularities in children's early *productions*, such as velar fronting (e.g., *cap* being pronounced *tap*; for a review see Smith, 2010, ch. 2 and 3), few studies have addressed the question of when and how young children *perceive* the regular phonological transformations that adult speakers of the target language apply.

Evidence suggests that by the end of their 1st year of life, infants show some sensitivity to allophonies (Pegg & Werker, 1997; Seidl et al., 2009), which introduce context-dependent phonetic variants. For instance, Pegg and Werker (1997) investigated English adults' and infants' perception of two alveolar stops (voiced unaspirated [d] and voiceless unaspirated [t]). In English, these sounds are never used on their own to contrast different words, and they occur in nonoverlapping distributions ([t] only occurs after [s], as in *stay*, and [d] occurs elsewhere, as in *day*). The authors show that younger infants (between 6 and 8 months of age) can distinguish between these two sounds, whereas older infants (10–12 months of age) and adults have problems perceiving this contrast. Such early adaptation to native allophonies may be explained by the fact that they are the easiest type of phonological alternations to acquire, being signaled by complementary distributions (Peperkamp & Dupoux, 2002). However, previous studies on allophony acquisition have only examined their impact on speech sound discrimination, not on lexical recognition or referent identification. Hence, they cannot attest to whether the sensitivity to allophonic variation influences the speed or accuracy of children's word recognition.

Aside from allophony, research has also examined children's perception of highly complex phonological alternations that are specific to certain lexical items and that are typically acquired much later. Sensitivity to French liaison, for instance, does not seem to be fully acquired even by the age of 6 years (Chevrot, Dugua, & Fayol, 2009; Dugua, Spinelli, Chevrot, & Fayol, 2009). This process inserts a lexically specified consonant at the end of certain words if they are followed by a vowel-initial word. For instance *petit* ''small'' can be realized with a final liaison consonant [t] (cf. *petit arbre* [pəti**t**aʁbʁə] ''small tree'' vs. *petit café* [pətikafe] ''small coffee''). There are several liaison consonants (the most frequent ones being [n], [z], and [t]), and given that they syllabify with the following vowel, learners find it hard to determine the lexical form of vowel-initial words (cf. *un arbre* [ɛ̃**n**aʁbʁə] ''a tree,'' *des arbres* [de**z**aʁbʁə] ''trees,'' *petit arbre* [pəti**t**aʁbʁə] ''small tree''). This is evident from children's classical mis-segmentation errors in their production of vowel-initial words (e.g., *le* ***n****arbre* for *l'arbre* ''the tree''; Chevrot et al., 2009). It is also difficult to distinguish between vowel-initial words to which a liaison consonant is added (as in the *arbre* [aʁbʁə] ''tree'' example given earlier) and consonant-initial words starting with those same consonants (such as *nez* [ne] ''nose'': *un nez* [ɛ̃**n**e] ''a nose,'' *des nez* [de**n**e] ''noses''). Furthermore, liaison is optional in certain sentence contexts (e.g., between verbs and object phrases), leading to more variability in the input, which makes it even harder to observe the regularities.

Our research investigates a third type of regularity, that is, assimilations. These are phonological alternations by which a feature of one sound spreads to an adjacent sound, causing it to change. Like many other languages, English allows for assimilation of place of articulation in alveolar consonants: Word-final alveolar stops and nasals, such as [t] and [n], can become labial, [p] or [m], respectively, when followed by a labial consonant, that is [p], [b] or [m]. For instance, the phrases *ten pounds* and *sweet baby* can be realized as *te[mp]ounds* and *swee[pb]aby*, respectively. This alteration is impossible in other, nonlabial contexts, such as [d]; thus, *ten dollars* and *sweet doll* can never be produced as *te[md]ollars* or *swee[pd]oll* (but note that English place assimilation can also apply before velar consonants; for example, *sweet girl* can be pronounced *swee[kg]irl*, a variant that is not investigated here). Assimilation can affect a range of other phonetic features (for a review, see Cho, 1999). French, for instance, allows for voicing assimilation in obstruents. For example, word-final voiceless [s] (as in *bus* ''bus'') can become voiced [z] when followed by a voiced obstruent like [v], but not in other contexts. Thus, the phrase *bus vert* ''green bus'' can be realized as *bu[zv]ert*, but *bus coloré* ''colorful bus'' cannot be realized as *bu[zk]oloré*.

The English and French assimilation processes described earlier are optional at word junctures and speakers vary with respect to the frequency and degree to which they apply them. For instance, a corpus analysis of transcriptions of naturally spoken American English (Dilley & Pitt, 2007) found that speakers produced word-final assimilations in 10% of the cases where it was possible (other frequent phenomena observed in these contexts were final consonant deletion and glottalization). Ellis and Hardcastle (2002) report articulatory measures in connected speech for 10 British English speakers. In this study, four speakers always assimilate completely, two never assimilate, and four show considerable intraspeaker variability, with two of them producing partial assimilations yielding segments half-way between labials and alveolars. The present study focuses on the most extreme cases, that is, complete assimilations. This type of assimilation is a particularly interesting phenomenon to study in the context of early word recognition, since it neutralizes an otherwise meaningful phonological contrast (in other contexts, the contrast between labials like [m] and alveolars like [n] is used to distinguish words in English, such as *mice* and *nice*). This neutralization interferes with lexical access to a greater extent than most allophonies, since it creates ambiguities between assimilated and nonassimilated segments. For instance, the sequence *ma[pm]aker* can be interpreted either as an assimilated version of *mat maker*, or as a standard version of *map maker*, as shown in Table 1.

In an elicited production task, Gaskell and Snoeren (2008) found that British English speakers indeed produce strong assimilations of [t] and [n] in 15%–20% of the cases. Furthermore, a subsequent forced-choice listening experiment demonstrated that these assimilations lead to lexical ambiguities like the ones described earlier.

Despite the complexity and variability of assimilations, adult listeners have been shown to apply rapid, implicit and automatic compensation mechanisms for them during lexical access. Marslen-Wilson, Nix, and Gaskell (1995) report, for instance, that English adults' recognition of visually presented words (e.g., *lean*) is facilitated when primed by aurally presented sentences containing a correctly assimilated form of the same words (e.g., *lea[mb]acon*). In contrast, such a facilitation effect was not observed when the prime was an incorrectly assimilated form (e.g., *lea[mg]ame*). Similar form priming effects have been found in French adults for sequences containing voicing assimilations (Snoeren, Ségui, & Hallé, 2008a, 2008b).

Table 1
Possible Realizations of ''Mat'' and ''Map'' in Different Contexts

	Assimilation context	No-assimilation context
Mat	ma[pm]aker	ma[ts]eller
Map	ma[pm]aker	ma[ps]eller

Adult listeners also show some sensitivity to non-native assimilations that they have never been exposed to in speech perception tasks (Gow & Im, 2004; Mitterer, Csépe, Honbolygo, & Blomert, 2006). Hence, the perceptual processing of assimilations relies in part on universal mechanisms that are independent of the particular language and type of assimilation involved. However, assimilation effects are substantially larger for native than for non-native assimilations in adults (Darcy, Peperkamp, & Dupoux, 2007; Darcy, Ramus, Christophe, Kinzler, & Dupoux, 2009; Mitterer, Csépe, & Blomert, 2006), showing that language-specific knowledge is also involved in adults' processing of assimilations.

So far, few studies have investigated the acquisition of assimilation. To our knowledge, only two studies with clinical populations have examined the processing of assimilation in school-age children. Both studies report that typically developing children, English 7-year-olds (Marshall, Ramus, & van der Lely, 2010) and Dutch 8-year-olds (Blomert, Mitterer, & Paffen, 2004), as well as older language- and reading-matched children with specific language impairment and dyslexia show adult-like compensation for native place assimilation in a word spotting task.

However, instances of assimilations in children's own productions have been reported at a much earlier age. Newton and Wells (2002) describe a single case study of a boy learning British English. He produces some assimilated forms even during the earliest testing session at age 2;4 years, and shows consistent adult-like behavior in assimilation environments from age 2;10 years on. To our knowledge, no studies to date have investigated whether children at such an early age are sensitive to their language's assimilations in perception, and whether they take them into account during word recognition. Indeed, compared to the acquisition of allophonies and that of lexically conditioned processes such as liaison, the acquisition of assimilation is of intermediate difficulty and could thus take place at an intermediate age.

On the one hand, in contrast to most cases of allophony, complete assimilations can create lexical ambiguities and hence interfere with word recognition. Furthermore, unlike allophonies, they are not signaled by complementary distributions. Thus, assimilations should be more difficult to acquire than allophonies (Peperkamp & Dupoux, 2002). On the other hand, assimilations lack the properties that make French liaison—which also creates lexical ambiguities—especially hard to acquire (i.e., the arbitrariness of both the words that undergo the process and the particular consonants that are inserted, as well as the ambiguous status of the liaison consonant, which is part of one word but syllabifies with another one). One may thus expect children to acquire sensitivity to native assimilations between the end of the 1st year of life (when sensitivity to allophonies emerges; Pegg & Werker, 1997; Seidl et al., 2009) and school age (when children come to master all aspects of liaison; Chevrot et al., 2009; Dugua et al., 2009).

In three experiments, we investigate how 2;5- to 3-year-old English and French toddlers cope with assimilations during word recognition. At this age, toddlers should know a sufficient number of assimilable words. They should also be able to master a picture pointing task designed to assess compensation for assimilation. In this task, toddlers are asked to point to one of two pictures, representing a familiar object (e.g., a pen) and an unfamiliar object (e.g., an astrolab). For each pair of pictures, the unfamiliar object is labeled with a nonword (e.g., *pem*) that differs minimally from the label of the familiar object (*pen*). The crucial test sentences contain this nonword in one of two phonological contexts: The first context licenses assimilation, that is, the nonword can be interpreted as an assimilated form of the familiar label (e.g., *Can you find the pe[mp]lease?*). As explained for the real English minimal pair *mat-map* earlier, this sentence is ambiguous: The sequence *pe[mp]lease* can either be interpreted as an assimilated form of the familiar label (*pen please*) or as the standard form of the novel, unfamiliar label (*pem please*). The second context does not license assimilation; here, the nonword can only refer to the unfamiliar object (*Can you find the pe[md]ear?*). If toddlers compensate for assimilation, they should point to the familiar object more often in response to the first type of sentences, which can be interpreted as containing assimilations, than to the second type of sentences, which cannot.

In Experiments 1 and 2 we examine compensation for native assimilations. Specifically, we test English toddlers on English place assimilation and French toddlers on French voicing assimilation. In Experiment 3 we investigate to what extent toddlers are sensitive to non-native assimilations by testing French toddlers on a hypothetical place assimilation rule that does not exist in French.

Experiment 1

Method

Material

Eighteen imageable monosyllabic English nouns ending in the alveolar nasal [n] or in the alveolar stop [t], for example *pen, boat*, were selected as test items (see Appendix A). They were all familiar to English-learning 30-month-old children according to the British Communicative Developmental Inventory (Hamilton, Plunkett, & Schafer, 2000; a British adaptation of the MacArthur CDI, Fenson et al., 1993). Each noun was matched to a nonword ending in the labial nasal [m] or stop [p] (*pem, boap*). Eighteen color images depicting the nouns were paired with images of unfamiliar objects of roughly the same size and visual complexity. The test items were used in four types of sentences, two for the control conditions and two for the experimental conditions. In the two control conditions, the familiar noun and the matched nonword appeared sentence-finally, as shown in (1).

(1)	*Control conditions:*	
	Familiar:	*Can you find the pen?*
	novel:	*Can you find the pem?*

(2)	*Experimental conditions:*	
	Assimilation:	*Can you find the pem please?*
	No-assimilation:	*Can you find the pem dear?*

In the two experimental conditions shown in (2), the nonword appeared sentence-medially, either before a labial consonant that hence licenses assimilation, or before another consonant that does not license assimilation.

All sentences were recorded by a female British English speaker. She produced all sentences fluently and without pauses in child-directed speech. The first and second authors checked that she did not produce prosodic boundaries between the nonwords and the following context, since this would prevent listeners from interpreting the nonwords as context-induced assimilations in the assimilation condition. The written sentences read by the speaker contained the orthographic transcription of the phonetic forms (i.e., *pen* and *pem*), as in the examples given earlier. The sentences in the assimilation condition thus contained extreme cases of assimilation.

A forced-choice perception experiment with adult speakers confirmed that the speaker indeed produced the nonword labels (not the real words) in all sentence-medial conditions and that assimilations thus were complete. Twelve monolingual British English speakers heard the final vowel-consonant portions of the targets (e.g., *em* from *Can you find the pem please?*) in the assimilation and in the no-assimilation conditions and were asked to label the final consonant. They were given the choice between the unassimilated (here, *n*) and the assimilated (here, *m*) consonant. They chose the assimilated consonant in 93.6% of the cases, and there was no significant difference between the two conditions (assimilation: 91.7%, no-assimilation: 95.4%), $t(11) = 1.17$, $p = .266$.

For the training phase, 10 familiar nouns ending with one of the nonalveolar nasals and stops [m], [p] and [k] (e.g., *lamb*, *soap, duck*) were matched to nonwords ending in their alveolar counterparts (*lan*, *soat*, *dutt*). They were recorded in the two control conditions only. Furthermore, three pairs of familiar nouns and phonologically more distant nonwords (e.g., *car – wug*) were recorded in the two control conditions for pretraining. As for the items in the test phase, images depicting the nouns were paired with images of unfamiliar objects for training and pretraining.

For both the test and the training phases, the speaker produced object labeling sentences for all nouns and matched nonwords (*This is a pen. … And that's a pem.*). Finally, the speaker recorded feedback sentences (e.g., *Very good!*, *Are you sure?*) and a child-friendly background story.

Procedure

The child was seated in front of a screen and two loudspeakers, with a parent sitting next to her. In some exceptional cases, she sat on the parent's lap. The parent was instructed not to talk to the child and not to interfere with the experiment in any way. The experimenter sat on the other side of the child and directed the experiment using a computer mouse. The setting was filmed from behind.

At the beginning of the experiment, the prerecorded background story was played. It was intended to motivate the child to participate and invited her to help a teddy bear in tidying up his room by pointing to the things he needed to put away. Next, the experiment unrolled in three parts: pretraining, training, and testing.

Pretraining phase. During pretraining the child was familiarized with the pointing task as described next. A diagram of the procedure and timing up to the critical pointing request can be found in Figure 1.

1. *Presentation*: A familiar object appeared on a randomly chosen side of the screen; 1.5 s later, this object was named by the corresponding presentation sentence (e.g., *This is a ball*). The object disappeared from the screen 1 s after naming. Following a further 1 s pause, where the screen remained blank, the yoked unfamiliar object was presented on the other side of the screen and was named (*And that's a bawk*) in keeping with the timing outlined earlier.
2. *Pointing request*: Both objects then reappeared simultaneously on the screen. After a 1.5 s silence, a prerecorded sentence directed the child to point to one of the two objects (e.g., familiar condition: *Can you find the ball?*). Based on the child's performance in earlier trials, the experimenter chose whether this sentence should ask for the familiar or the unfamiliar object. Using the mouse button (left picture = left button, right picture = right button), she registered which side the child pointed to. The experimenter's coding was not visible to the child.

The first trial always asked for the familiar object, to make the first pointing response as easy as possible. In subsequent trials, the experimenter based her decision on whether to launch a trial for the familiar or the unfamiliar object on the performance of the child so far: If the child showed a bias (either always pointing to the familiar or always pointing to the unfamiliar object), the experimenter countered this bias, otherwise she kept a more or

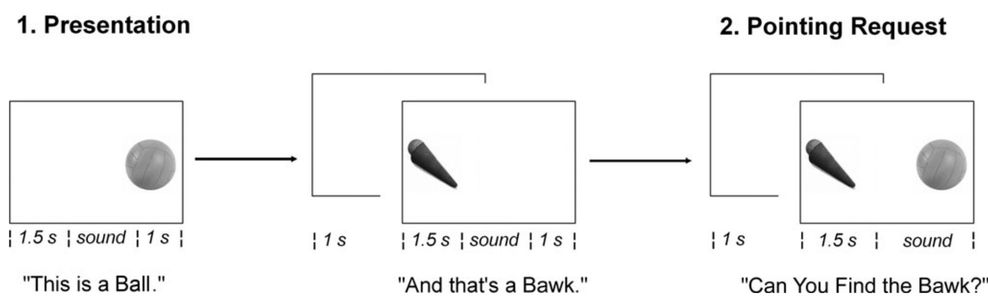

Figure 1. Example of presentation and pointing request in a pretraining trial.

less equal count of familiar and novel trials. If the child did not point spontaneously during pre-training or training, the experimenter or, if needed, the parent helped her and the trial was repeated. The experimenter also reminded the child to point, repeated the stimuli and complimented the child enthusiastically if necessary.

3. *Feedback*: If her response was correct, the child was given positive feedback. This involved the correct object jumping around the screen, accompanied by a pre-recorded sentence praising the child (e.g., *Well done*!). This was followed by the teddy appearing on the screen, with an increasing number of stars below him for every correct response to reward the child. If the response was incorrect, she was invited to try again and the pointing request was repeated until her response was correct. The experimenter then decided whether to launch another pointing request for the same object pair, or to move on to the next pair if the child's reactions were deemed sufficiently good.

Training phase. Because toddlers have difficulties in distinguishing subtle sound contrasts in words in explicit tasks (e.g., Garnica, 1973), they were further trained on detecting place changes in the pointing task before being tested on their knowledge of assimilations. The procedure for training was similar to the pre-training phase described earlier, differing only in that the label for the unfamiliar object formed a minimal pair with the label for the yoked familiar object (e.g., *duck* vs. *dutt*). If the child provided four correct responses within five consecutive trials on her first try during training, she progressed to the test phase. If she failed to reach this criterion within 15 trials, the experiment ended. We chose this relatively lax criterion because any more stringent criterion would have made the training phase a lot longer, and children would have been less concentrated during the test phase. Note that we cannot interpret successful training to prove that children can distinguish the minimal pairs.

Test phase. At the beginning of the test phase, the experimenter put on headphones with masking voices that ensured she could not hear what the child was being asked to point to. In the background story, the child was told that the teddy had found a big bag with objects he wanted to show her. The test phase consisted of 18 trials, each involving the presentation of two objects and a pre-recorded sentence directing the child to point at one of the two images presented on the screen. The trials followed a similar format to those in the training phase, with a few key differences. First, no corrective feedback was given. Second, if the child failed to point, the experimenter reminded her to do so without naming the objects. Third, at the end of each trial, the objects spun around each other accompanied by blinking stars and cartoon music to keep the child motivated. Fourth, at the beginning of each trial, the teddy appeared on the screen with a big bag, and the child was instructed to look at the objects he was taking out of it that were then presented on the screen by means of the same procedure as during training. In order for the child to be able to monitor her progress in the experiment, the teddy's bag reduced in size from trial to trial, until it was empty at the end of the test phase.

Presentation of objects in the different conditions was counterbalanced across subjects. Familiar and unfamiliar objects were yoked together across conditions. Each object pair was used only once. Each child was presented with six control trials – three in the Familiar condition (e.g., *Can you find the pen*?) and three in the novel condition (e.g., *Can you find the pem*?)—and 12 experimental trials—six in the assimilation condition (e.g., *Can you find the pem please*?) and six in the no-assimilation condition (e.g., *Can you find the pem dear*?). The 18 trials were presented in pseudo-random order, with the constraint that the first one was a control trial. The entire experiment lasted 4–15 min, depending on whether or not the child reached the test phase.

Participants

Eighteen monolingual British English children (11 girls and 7 boys) participated in the experiment. Their age ranged from 29 to 32 months (average= 30 months). Data from 17 additional children were rejected because of failure to reach training criterion (n = 8), failure to complete the test phase due to fussiness or task refusal (n = 4), or because 50% or more of the test trials were excluded (see rejection criteria next, n = 5).

Results and Discussion

Based on off-line coding, we excluded trials in which (a) either the child, the experimenter, or the parent spoke during the pointing request; (b) the experimenter had to remind the child to point; or (c) the child pointed too early (before the critical word was presented) or to both objects (simultaneously or in alternation). Children for whom 50% or more of the trials had to be excluded were withdrawn from the sample. In the final sample, 20.4% of the test trials were excluded (familiar: 16.7%, novel: 16.7%, assimilation: 19.5%, no-assimilation: 25.0%). We then calculated the mean percentages of pointing to the familiar object in the remaining trials per child and per condition, based on the on-line, blind coding by the experimenter. Figure 2 shows these proportions averaged across participants by condition.

Like in previous studies on assimilation (Darcy et al., 2009; Mitterer, Csépe, Honbolygo, et al., 2006), our analyses focus on differences between conditions, taking the control conditions as reference points, rather than on absolute values or comparisons to chance level. Possible biases toward the familiar or novel object are thus neutralized. Paired two-tailed t tests were used to analyze differences between conditions, and Cohen's d effect size measures using pooled variances are given. Since some authors claim that parametric tests are unsuitable for categorical data (e.g., Jaeger, 2008), our analyses repeated all our analyses with nonparametric Wilcoxon tests, which yield very similar results. With regard to the control conditions, children pointed to the familiar object significantly more often in the familiar than in the novel condition (familiar: 75.9%, novel: 20.4%), $t(17) = 4.61$, $p < .001$, $d = 1.65$. That is, children were more likely to point to the image of the pen upon hearing the sentence *Can you find the pen?* than upon hearing the sentence *Can you find the pem?* This result suggests that they had no major difficulties with the task and that they were able to discriminate between the members of the minimal pairs reasonably well. Thus, most 29- to 32-month-old English children can be trained to distinguish differences in place of articulation in sentence-final sounds in a pointing task.

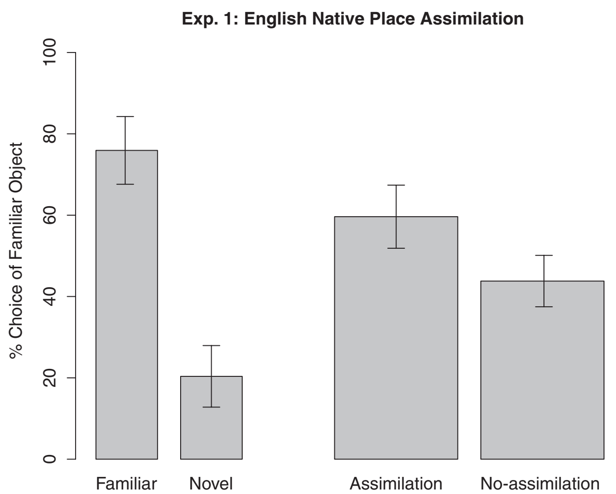

Figure 2. Mean percentages of choice of the familiar object by condition in Experiment 1. Bar width is proportionate to the number of items per condition. Error bars represent ± 1 *SE*.

With respect to the experimental conditions, toddlers pointed significantly more often to the familiar object in the assimilation than in the no-assimilation condition (assimilation: 59.6%, no-assimilation: 43.8%), $t(17) = 2.68$, $p = .016$, $d = 0.53$. That is, they were more likely to point to the pen upon hearing the sentence *Can you find the pem please?* than the sentence *Can you find the pem dear?* showing that they compensate for native place assimilation.

Children's scores in the experimental conditions were then compared to the control conditions with paired tests. First, scores in the assimilation condition did not differ significantly from those in the familiar condition, $t(17) = 1.40$, $p = .18$, but scores in the no-assimilation condition were significantly smaller than those in the familiar condition, $t(17) = 3.40$, $p = .003$, $d = 1.03$. These analyses show that children treat the target word (e.g., *pem*) as more similar to the familiar label (e.g., *pen*) in the assimilation than in the no-assimilation condition, confirming that they compensate for assimilation. Second, scores in the assimilation, $t(17) = 4.55$, $p < .001$, $d = 1.21$, and in the no-assimilation, $t(17) = 3.17$, $p = .006$, $d = 0.80$, conditions were significantly greater than those in the novel condition. The latter comparison shows that children have a greater bias to choose the familiar object upon hearing the novel label in sentence-medial than in sentence-final position, regardless of the following context.

Summing up, these results show that, like adult listeners, those 29- to 32-month-old English toddlers who show sensitivity to word-final place changes in a pointing task also compensate for place assimilation. Note that since only those children who successfully passed training went on to take part in the assimilation test, we cannot comment on the ability of the other children—that is, those who failed the training phase—to compensate for assimilation. Thus, English children are sensitive to native place assimilation more than 4 years earlier than demonstrated before (Blomert et al., 2004; Marshall et al., 2010).

In the next experiment, we test another assimilation type to examine the generality of our findings. Specifically, we test French toddlers on voicing assimilation. In contrast to place assimilation tested in the first experiment, which is an extremely frequent process in the languages of the world (Blevins, 2004), French voicing assimilation is phonologically more unusual because it makes voicing spread symmetrically (Lombardi, 1995; but see Wetzels & Mascaró, 2001): Both voiced obstruents can become voiceless (when followed by another voiceless obstruent), and voiceless obstruents can become voiced (when followed by another voiced obstruent). English place assimilation, however, like most assimilation rules, is asymmetrical: Alveolars can become labials (or velars) but not vice versa. An analysis of the phonological patterns of 548 languages of the world described in a database compiled by Mielke (2007) confirms that symmetrical voicing assimilation in consonants is less common than asymmetrical place assimilation: Some form of the former is found in 25 languages, whereas some form of the latter is found in 75 languages in the database. Thus, asymmetrical place assimilation is 3 times more common than symmetric voicing assimilation.

Experiment 2 tests whether French toddlers compensate for the more unusual process of voicing assimilation, just as English toddlers do for the more common place assimilation in Experiment 1, using the same methodology.

Experiment 2

Method

Material

Twelve imageable monosyllabic French words ending in one of the obstruents [t], [b], [s], [z], [ʃ], or [ʒ], for exampl *bus* [bys] ''bus'', *robe* [ʁɔb] ''dress,'' were selected as test items (see Appendix B). They were all reported to be familiar to French-learning 30-month-old children according to a French adaptation (Kern & Gayraud, 2010) of the MacArthur CDI (Fenson et al., 1993). Each noun was matched to a nonword ending in an obstruent with the opposite voicing value (*buz* [byz], *rope* [ʁ ɔp]). Twelve images depicting the nouns were paired with images of unfamiliar objects of roughly the same size and visual complexity. Familiar and unfamiliar objects were yoked together across conditions. As in Experiment 1, the test items were recorded in four sentences, two for the control conditions, as shown in (3), and two for the experimental conditions, as shown in (4).

(3)		*Control conditions:*	
	Familiar:	*Montre le bus!*	''Show the bus!''
	novel:	*Montre le buz*!	''Show the [byz]!''

(4)		*Experimental conditions:*	
	Assimilation:	*Montre le bu[zd]e Paul!*	''Show Paul's bus/[byz]!''
	No-assimilation:	*Montre le bu[zl]à-bas!*	''Show the [byz] over there!''

In the assimilation condition, nonwords that end in a voiced obstruent are followed by another voiced obstruent, and nonwords that end in a voiceless obstruent are followed by another voiceless obstruent. In the no-assimilation condition, the nonwords are followed by a sonorant, which does not license assimilation.

All sentences were recorded by a female French speaker. She read them fluently and without pauses in child-directed speech. The written material contained the orthographic transcription of the phonetic forms (hence, *bus* for [bys] and *buz* for [byz]), as in the examples given earlier, yielding extreme cases of assimilation in the assimilation condition. A perception experiment using the same forced-choice methodology as given earlier confirmed that the speaker produced the nonwords in all sentence-medial conditions. Twelve monolingual French adult speakers chose the assimilated consonant in 94.4% of the cases, and there was no significant difference between conditions (assimilation: 92.3%, no-assimilation: 96.5%), $t(11) = 1.73$, $p = .111$.

Furthermore, 10 additional familiar nouns ending in a voiced or voiceless obstruent were recorded for training in the two control conditions only (e.g., *sac* [sak] ''bag''). They were matched to nonwords ending in an obstruent with the opposite voicing value (e.g., *sag* [sag]). In addition, three pairs of familiar nouns and phonologically distant nonwords (e.g., *balle* [bal] ''ball'' – *kim* [kim]) were recorded in the two control conditions for pretraining. As for the items in the test phase, images depicting the nouns were paired with images of unfamiliar objects.

For both the test and the training phase, the speaker produced sentences that labeled the objects using the nouns and matched nonwords (e.g., *Ceci est un bus*. ''This is a bus.'' *Et ça, c'est un buz*. ''And this is a [byz].''). Finally, the speaker recorded feedback sentences (e.g., *Très bien!* ''Very good!'' *Essaie encore!* ''Try again!'') and a child-friendly background story (the same as in Experiment 1, but translated into French).

Procedure

The procedure was the same as in Experiment 1, except for the fact that the parent wore headphones with masking voices throughout the procedure.

Participants

Twenty-seven monolingual French children (14 girls and 13 boys), participated in the experiment. Their ages ranged from 29 to 36 months (M = 32 months). Data from 28 additional children were rejected because of failure to reach training criterion (n = 15), failure to complete the test phase due to fussiness or task refusal (n = 5), failure to point to one of the sides (n = 1, note that, by coincidence, the correct answer was always on the same side during pretraining and training for this child, probably inducing this bias during the test phase.), or because 50% or more of the test trials were excluded (see rejection criteria, n = 7).

Results and Discussion

On the basis of the same criteria as in Experiment 1, 16.0% of the test trials were excluded (familiar: 20.4%, novel: 18.5%, assimilation: 14.8%, no-assimilation: 13.9%). The remaining data were analyzed as in Experiment 1. Figure 3 shows average scores per condition.

In control trials, children chose the familiar object significantly more often in the familiar than in the novel condition (familiar: 77.1%, novel: 26.9%), $t(22) = 4.04$, $p < .001$, $d = 1.21$, suggesting that they had no major difficulties with the task. With regard to the experimental conditions, children pointed significantly more often to the familiar object in the assimilation than in the no-assimilation condition (assimilation: 68.5%, no-assimilation: 51.2%), $t(26) = 2.75$, $p = .011$, $d = 0.56$, thus showing compensation for assimilation.

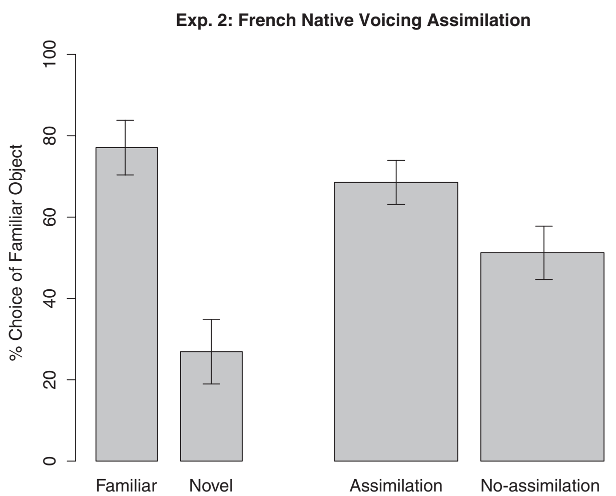

Figure 3. Mean percentages of choice of the familiar object by condition in Experiment 2.
Note. Bar width is proportionate to the number of items per condition. Error bars represent ± 1 *SE*.

Furthermore, scores in the assimilation condition did not differ significantly from those in the familiar condition, $t(23) = 1.12$, $p = .275$, whereas scores in the no-assimilation condition were significantly smaller than those in the familiar condition, $t(23) = 3.25$, $p = .004$, $d = 0.89$. As for Experiment 1, these results corroborate the assimilation effect, since children treat the target as more similar to the familiar form in the assimilation than in the no-assimilation condition. Both in the assimilation, $t(25) = 3.99$, $p < .001$, $d = 1.19$, and in the no-assimilation condition, $t(25) = 2.63$, $p = .014$, $d = 0.63$, scores were significantly greater than those in the novel condition, showing that, as in Experiment 1, children have a greater overall bias to choose the familiar object upon hearing the novel label in sentence-medial than in sentence-final position.

To compare the strength of the assimilation effects cross-linguistically, individual assimilation scores were computed for both Experiment 1 and Experiment 2 by subtracting each toddler's score in the assimilation condition from the one in the no-assimilation condition. Assimilation scores for the English toddlers in Experiment 1 (M: 15.9%) did not differ significantly from French toddlers' assimilation scores in Experiment 2 (M: 17.3%) in an independent two-tailed t test, $t(43) < 1$. Overall accuracy in the control conditions was computed for all children by averaging their proportion of pointing to the familiar object in the familiar condition and to the unfamiliar object in the novel condition. These scores did not differ between the two experiments (Experiment 1: 77.78%, Experiment 2: 75.31%), $t(43) < 1$.

These results show that 29- to 36-month-old French children already exhibit context-specific compensation for voicing assimilation, just as English toddlers do for place assimilation in Experiment 1. Moreover, both toddler groups seem to compensate to an equal extent for their native language's assimilations.

In the next experiment, we test whether or not toddlers' compensation abilities are already influenced by language-specific experience with the type of assimilations that occur in their native language. Adult studies suggest that the perception of assimilations involves both language-independent and language-specific processes.

On the one hand, several studies reveal universal sensitivity to assimilations. For instance, in two phoneme detection experiments on Hungarian voicing assimilation reported in Gow and Im (2004), both Hungarian and English listeners were faster in assimilated than in unassimilated contexts, even though the English speakers had no experience with Hungarian voicing assimilation. Likewise, using event-related potentials with an odd-ball paradigm, Mitterer, Csépe, Honbolygo, et al. (2006) found that Hungarian and Dutch adults react similarly to liquid assimilation ([l] being pronounced as [r] before another [r]), an alternation that applies in Hungarian, but not in Dutch.

On the other hand, language-specific assimilation effects have been reported over and above language-independent effects. For instance, Mitterer, Csépe, and Blomert (2006) compared the processing of the same Hungarian liquid assimilation mentioned earlier in a discrimination versus an identification task. Hungarian listeners had more difficulties than Dutch listeners in distinguishing viably assimilated forms from nonassimilated forms in the identification task, showing that they compensated more for this assimilation than the Dutch listeners. However, no differences according to the listeners' language were found in the discrimination task. This suggests that language experience enhances compensation for assimilation, but only in tasks that involve lexical access. Another word recognition study examining the processing of assimilation by French and English adults confirmed the existence of both language-independent and language-specific effects, with the language-specific ones being substantially larger (Darcy et al., 2009). Finally, a similar study also found language-specific effects in second language learners, that is French learners of English and English learners of French (Darcy et al., 2007).

Our last experiment examines whether such language-specific effects can be attested in first language acquisition, by testing toddlers' processing of assimilations that do not apply in their native language. Since asymmetric place assimilation occurs more frequently in the languages of the world than symmetric voicing assimilation, it is a good candidate to be covered by any universal compensation process. Experiment 3, therefore, tests French toddlers on a hypothetical asymmetrical place assimilation rule (which does not apply in French). If early perception of assimilation relies exclusively on language-independent processes, French toddlers should compensate for this non-native assimilation to the same extent as they did for native assimilations in Experiment 2. If, by contrast, language-specific experience comes into play by 3 years of age, they should compensate significantly less (or not at all).

Our hypothetical assimilation rule is similar but not identical to English place assimilation examined in Experiment 1. Cross-linguistically, place assimilation applies most often to stops and nasals (Mohanan, 1993), as in the English example examined in Experiment 1. Ideally, we would thus use only these consonants for our hypothetical rule. There are, however, not enough suitable imageable monosyllabic nouns ending in [t], [d], and [n] in French toddlers' early vocabularies. Given that forms of fricative place assimilation are rare, but exist as well, for instance in German (Niebuhr, Lill, & Neuschulz, 2011) and Sanskrit (Allen, 1962), we also include the fricatives [s] and [z] as targets for assimilation.

Experiment 3

Method

Material

Twelve imageable monosyllabic French nouns ending in one of the alveolar consonants [t], [n], [s], or [z], e.g., *lune* [lyn] ''moon,'' *bus* [bys] ''bus'' (see Appendix C) were selected as test items. They were all familiar to French-learning 30-month-old children according to a French adaptation (Kern & Gayraud, 2010) of the MacArthur CDI (Fenson et al., 1993). Each noun was matched to a non-word ending in a corresponding labial consonant (*lume* [lym], *buf* [byf]). Twelve images depicting the nouns were paired with images of unfamiliar objects. The test items were recorded in four sentences, two for the control conditions, as shown in (5), and two for the experimental conditions, as shown in (6).

(5)		*Control conditions:*	
	Familiar:	*Montre la lune!*	''Show the moon!''
	novel:	*Montre la lume*!	''Show the [lym]!''

(6)		*Experimental conditions:*	
	Pseudo-assimilation:	*Montre la lu[mp]ar ici!*	''Show the [lym] over here!''
	No-assimilation:	*Montre la lu[md]e Paul!*	''Show Paul's [lym]!''

In the pseudo-assimilation condition, the non-words are followed by a labial consonant. Sentences in this condition would be ambiguous if the hypothetical place assimilation rule were applicable in French (i.e., *lume* could be interpreted either as assimilated *lune* ''moon'' or as a novel word). If, however, French children know that place assimilation does not apply in French, they should interpret *lume* unambiguously as a novel word. In the no-assimilation condition, the nonwords are followed by a nonlabial consonant. Hence, sentences in this condition are unambiguous (i.e., *lume* can only be interpreted as a novel word), regardless of the context.

Thus, if French toddlers compensate for non-native assimilations such as our hypothetical place assimilation, they should show the same pattern as in the two previous experiments; that is, they should point more often to the familiar object in the pseudo-assimilation than in the no-assimilation condition. In contrast, if they do not compensate for non-native place assimilation, they should point to the familiar object equally rarely in the pseudo-assimilation and in the no-assimilation condition. All sentences were recorded without pauses in child-directed speech by a female French speaker (the same speaker as in Experiment 2). The written materials contained the orthographic transcription of the phonetic forms (hence, *lune* for [lyn] and *lume* for [lym]), as in the examples given earlier. As in Experiments 1 and 2, the sentences in the assimilation condition thus contained extreme cases of the hypothetical assimilation. Again, a forced-choice control experiment showed that the speaker indeed produced the nonwords. Twelve monolingual French speakers chose the pseudo-assimilated version in 97.6% of the cases, and there was no significant difference between conditions (pseudo-assimilation: 98.6%, no-assimilation: 96.5%), $t(11) = 1.39$, $p = .191$.

Ten imageable, familiar nouns ending in a labial or a velar consonant (e.g., *sac* [sak] ''bag'') were recorded for training in the two control conditions only. They were matched to nonwords ending in an alveolar consonant (e.g., *satte* [sat]). As for the items in the test phase, images depicting the nouns were paired with images of unfamiliar objects.

For both the test and the training phases, the speaker produced sentences labeling the objects with the nouns and matched nonwords (e.g., *Ceci est une lune*. ''This is a moon.,'' *Et ça, c'est une lume*. ''And this is a [lym].''). The pre-training, feedback, and background story sentences were the same as in Experiment 2.

Procedure

The procedure was the same as in Experiment 2.

Participants

Twenty-seven monolingual French children (15 girls and 12 boys) participated in the experiment. Their age ranged from 29 to 36 months (average = 33 months) and was not significantly different from that of the children in Experiment 2, independent two-tailed t test: $t(52) < 1$. Data from 26 additional children were rejected because they failed to reach training criterion ($n = 17$) or to complete the test phase ($n = 1$), or because 50% or more of the test trials were excluded ($n = 8$).

Results and Discussion

On the basis of the same criteria as in Experiments 1 and 2, 16.0% of the test trials were excluded (familiar: 18.5%, novel: 12.9%, pseudo-assimilation: 12.9%, no-assimilation: 19.4%). The remaining data were analyzed as before. Figure 4 shows average scores per condition.

As in the previous two experiments, scores in the control conditions differed significantly from each other (familiar: 86.5%, novel: 20.0%), $t(23) = 9.47$, $p < .001$, $d = 2.32$, showing that the children had no major difficulties with the task. With regard to the experimental conditions, there was no significant difference between the pseudo- and the no-assimilation conditions (pseudo-assimilation: 26.9%, no-assimilation: 35.2%), $t(26) = 1.19$, $p = .246$, showing that children do not compensate for the hypothetical assimilation rule. They chose the famil-

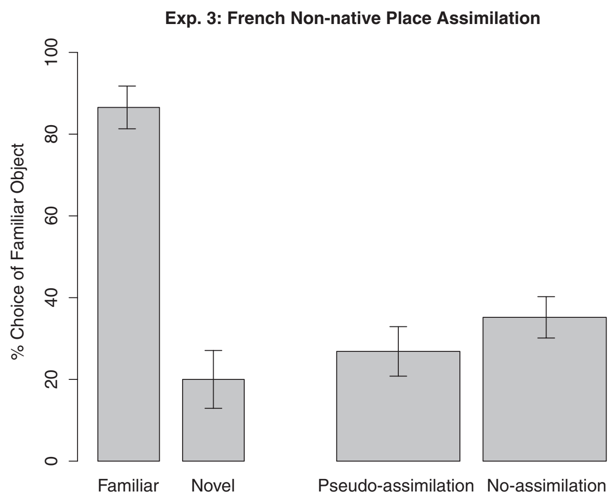

Figure 4. Mean percentages of choice of the familiar object by condition in Experiment 3.
Note. Bar width is proportionate to the number of items per condition. Error bars represent ± 1 *SE*.

iar object less often than in the familiar condition in both the pseudo-assimilation, $t(25) = 8.00$, $p < .001$, $d = 2.01$, and the no-assimilation, $t(25) = 9.07$, $p < .001$, $d = 1.95$, conditions. Moreover, scores in the novel condition differed from those in the no-assimilation condition, $t(24) = 2.40$, $p = .025$, $d = 0.48$, but not from those in the pseudo-assimilation condition, $t(24) < 1$. Children thus tended to interpret the target word (e.g., *lume*) as the label of the unfamiliar object in the experimental conditions (and, if anything, more so in the no-assimilation than in the pseudo-assimilation condition).

As before, individual assimilation scores (defined as subtractions of the score in the pseudo-assimilation condition from that in the no-assimilation condition) were computed and compared with those of Experiments 1 and 2. Assimilation scores in the present experiment (−8.3%) were significantly smaller than those in Experiment 1, $t(43) = 2.45$, $p = .019$, $d = 0.78$, and those in Experiment 2, $t(52) = 2.72$, $p = .009$, $d = 0.74$, whereas overall accuracy in the control conditions in this experiment (81.4%) was not significantly different from the one in Experiment 1 (77.8%), $t(43) < 1$, and in Experiment 2 (75.3%), $t(52) < 1$.

Thus, contrary to the two previous experiments, there are no signs of compensation for assimilation in this experiment. Might this failure be due to the presence of test items with final fricatives ([s], [z]), for which—as explained earlier—assimilation is cross-linguistically rare and less natural than for stops and nasals ([t], [n])? We investigated this possibility by carrying out restricted analyses for items ending with stops and nasals only (which represented half of the experimental items). They yielded results similar to the global analyses: Scores in the control conditions differed significantly from each other (familiar: 82.5%, novel: 23.8%), $t(19) = 7.80$, $p < .001$, $d = 1.97$, whereas there was no significant difference between the two experimental conditions (pseudo-assimilation: 27.4%, no-assimilation: 37.7%) $t(20) = 1.22$, $p = .236$. Children pointed to the familiar object significantly more often in the familiar condition than in both the pseudo-assimilation, $t(19) = 6.28$, $p < .001$, $d = 1.74$, and the no-assimilation, $t(19) = 6.93$, $p < .001$, $d = 1.56$, conditions. Scores in the novel condition were not significantly different from those in the pseudo-assimilation, $t(20) < 1$, and marginally different from those in the no-assimilation condition, $t(20) = 1.89$, $p = .073$, $d = 0.42$. These results are very similar to the overall results, and there are no signs of compensation for assimilation for this restricted stimulus set. Hence, the presence of test items with consonants that cross-linguistically assimilate less often does not explain the failure of toddlers to compensate for assimilation in this experiment.

To sum up, 29- to 36-month-old French children do not compensate for non-native place assimilation, not even when it is applied to consonants like [t] and [n], for which place assimilation is very common cross-linguistically. The results, therefore, provide evidence that the context-sensitive compensation for native assimilation observed in Experiments 1 and 2 is already specific to the native language of the toddlers.

General Discussion

Using a picture pointing task, we show that those 2;5- to 3;0-year-old English and French children who successfully discriminate subtle word-final consonant changes also compensate for assimilations that apply in their native language. Children's sensitivity to native assimilations thus emerges before the age of 3 years, considerably earlier than reported before (cf. school-age children tested in Blomert et al., 2004; Marshall et al., 2010). Furthermore, French toddlers do not show any compensation effect for a hypothetical, non-native, place assimilation rule, not even when applied to sounds that most frequently undergo this process in the languages of the world. In what follows, we discuss the pattern of results obtained across the three experiments in detail.

First of all, it is worth noting here that most of the toddlers could be trained to pay attention to word-final consonant changes, as indicated by their good performance in the control conditions during the test phase. Earlier findings that toddlers are able to distinguish word-final consonant minimal pairs from each other and correctly associate the novel form of the minimal pair with the unfamiliar object obtained in implicit preferential looking tasks (Nazzi & Bertoncini, 2009; Swingley, 2009) can thus be extended to our more explicit pointing task. However, as noted also by Garnica (1973) in object manipulation tasks, some toddlers found distinguishing between members of a minimal pair quite difficult: About a quarter of the participants did not pass our relatively lenient training criterion of four correct of five trials (22% in Experiment 1, 27% in Experiment 2, 32% in Experiment 3).

Overall performance in the experimental conditions was worse than in the control conditions, a difference which is most likely due to the fact that in the control conditions the critical target words were used in a more salient position (sentence-finally; i.e., *Can you find the pem?*) than in the experimental conditions (sentence-medially; i.e., *Can you find the pem dear?*). Nevertheless, both English (Experiment 1) and French (Experiment 2) toddlers chose the familiar object significantly more often when the target word in the stimulus sentence could be interpreted as an assimilated variant of the familiar noun (assimilation condition; i.e., *Can you find the pem please?*) than when it could not (no Assimilation condition; i.e., *Can you find the pem dear?*). This difference in behavior shows that English and French toddlers take native assimilations into account during word recognition, just as adult speakers of both languages do (Darcy et al., 2009). Note that the minimal pair training and the object presentations could not have interfered with toddlers' compensation for assimilation, since during the training the target words were only presented sentence-finally, where assimilation cannot apply. It is also noteworthy that the toddlers in our study show compensation for fully assimilated tokens, which is the strongest form of assimilation.

We found that English and French toddlers show compensation effects for their respective native assimilations of similar magnitude. This contrasts with adult findings, where French speakers compensate significantly more than English speakers (Darcy et al., 2009). However, the compensation effect is overall much smaller in both toddler groups than in the adults tested by Darcy et al. (2009), which may have obscured any cross-linguistic differences.

It would be interesting to analyze whether or not compensation for assimilation is stronger for specific consonant classes (e.g., stops vs. nasals in Experiment 1, voiced vs. voiceless sounds in Experiment 2), since assimilation frequency and strength can vary according to the segments involved (Dilley & Pitt, 2007; Snoeren, Hallé, & Ségui, 2006). However, the number of assimilable words that toddlers know limits the items that could suitably address this issue. Similarly, correlations between children's assimilation performance and their vocabulary and general language skills could be explored. We were not able to collect such measures in the present study since the children were already too old for standard parental questionnaires like the MacArthur CDI (Fenson et al., 1993), and adding a standardized language test to our already demanding pointing task might have overstrained our young participants.

Our finding that French toddlers do not compensate for a hypothetical rule of place assimilation extends the growing body of evidence that language-specific experience plays a role in compensation for assimilation in tasks involving word recognition from adults (Darcy et al., 2007; Darcy et al., 2009; Mitterer, Csépe, Honbolygo, et al., 2006) to young children. Note that, in contrast to most adult studies, which report at least a small compensation effect for non-native assimilations (Darcy et al., 2007; Darcy et al., 2009; Gow & Im, 2004; Mitterer, Csépe, & Blomert, 2006; Mitterer, Csépe, Honbolygo, et al., 2006), we did not find any language-independent compensation effect for non-native assimilation at all, not even for those consonants typically targeted by place assimilation cross-linguistically (i.e., [t] and [n]). Again, this difference could be due to the fact that our child pointing paradigm is less sensitive than the ones used with adults. Toddlers might show language-independent effects in other tasks. Likewise, they might show such effects when tested on stimuli with partial assimilations, which do not create lexical ambiguity and where bottom-up recovery of the canonical form should be easier.

The contrast between children's performance with native and non-native assimilations also sheds light on children's treatment of native language assimilations. One possible explanation for children's greater acceptance of viable assimilations in their native language would be that these may be perceived as less salient mispronunciations of the familiar word. Even 2-year-old children show surprising flexibility in their recognition of coarticulated words: They recognize a target label equally well when it is presented on its own in citation form compared to when it is presented in a sentence, where the surrounding context of the sentence may distort the pronunciation of a word due to coarticulation (e.g., *dog* in *Look at the dog over there*; Plunkett, 2005). Although the coarticulated words tested in Plunkett did not contain instances of assimilation, the ease with which the 2-year-olds accepted coarticulated word forms raises the possibility that assimilations such as *pem please* are treated as better coarticulated word forms (due to greater acoustical or featural overlap between the assimilated segment and the surrounding context). In contrast, feature changes in the target word in other contexts, such as in *pem dear*, are more salient distortions because there is no such featural or acoustic overlap. In other words, toddlers successfully recognize the target when presented with feature changes that can be interpreted as assimilations but not when presented with the same feature changes in other contexts. Although such an argument might explain toddlers' responding to native language assimilations, the contrast in their performance following native and non-native language assimilations highlights problems with this argument. If toddlers' responding were merely due to the lesser salience of the changes in an assimilation context as opposed to other contexts, we would have expected them to react similarly to non-native assimilations, since they involve a similar degree of acoustical and featural overlap. The absence of such an effect for non-native assimilation strongly suggests that their improved recognition of target labels that undergo native assimilations is influenced by experience with assimilations that is specific to their native language.

The present results raise questions as to when and how language-specific knowledge about assimilations is acquired. Concerning the age of acquisition, it would of course be necessary to test younger children. Given that it is very hard to train children below age 2;6 years to point to members of minimal pairs on request, such experiments should use less demanding methods, for instance intermodel preferential looking or event-related potentials. Testing younger children would also allow us to gain insight into how language-specific knowledge develops. One possibility is that children's initial grammar contains no assimilation rules at all, and that children have to learn their native language's assimilation rules (Peperkamp & Dupoux, 2002). We would thus expect younger children to show no compensation for native assimilation. Alternatively, assimilations might be universal default processes that are overrepresented in early grammar. According to some accounts of phonological acquisition, children would indeed be sensitive to both native and non-native assimilations initially, and have to ''unlearn'' the non-native ones with greater native language experience (Donegan & Stampe, 1979; Smolensky, Davidson, & Jusczyk, 2000). The prediction would thus be that younger children compensate both for native and non-native assimilations.

Knowledge about the age of acquisition would also help us understand the underlying learning mechanisms. Indeed, we can identify three possible sources of information that toddlers could use and that become available at different ages. First, they could rely on semantic knowledge. For instance, once they know a number of obstruent-final words and their meanings, French toddlers can observe that some word forms they hear, like *bus* and *bu[z]* (as in the sentence *Montre le bu[z] de Paul!* ''Show Paul's bus!''), refer to the same object, and hypothesize that they are related by a voicing assimilation process. They could also observe that *lune* does not have a variant *lu[m]*, and thus conclude that place assimilation does not apply in French. Interestingly, alternative pronunciations of early acquired concrete nouns such as *bus* and *bu[z]* often occur within a short time lag in the input. Two examples with the item *singe* [sɛ̃ʒ] ''monkey'' drawn from the French Champaud corpus in the Childes database (MacWhinney, 2000) are shown in [7] (the three utterances in [7a] were produced in sequence); note that in both examples, *singe* occurs once in a clear nonassimilation context, phrase-finally or before a vowel, and once in a clear assimilation context, before *qui* [ki].

(7) a. *C'est le **singe** qui veut monter.*
''It's the monkey who wants to go up.''
*Regarde, cherche le **singe**.*
''Look, find the monkey.''
*Le **singe** est dans l'arbre, sur les bras.*
''The monkey is in the tree, on its arms.''
b. *Les petits **singes**, ce sont des **singes** qui font les petits **singes**.*
''(As to) baby monkeys, it's monkeys who make baby monkeys.''

The fact that these different tokens cluster together is not a coincidence, since concrete nouns, the largest word class in children's early vocabulary (Brown, 1957), are typically conversational topics, whose distribution tends to be bursty (see Altmann, Pierrehumbert, & Motter, 2009, and references therein). The occurrence of assimilated and nonassimilated instances of the same word within a short time lag might help children in acquiring the assimilation rule.

A second source that toddlers may use to learn about assimilations is distributional information (Peperkamp, 2003; Peperkamp & Dupoux, 2002): They might track the distributions of frequent word forms for which they have not assigned a meaning yet and observe irregularities in some cases. For instance, *chaque* [ʃak] (''every'') is a frequent French function word that few young children understand. Its assimilated form, [ʃag], occurs before voiced obstruents only, and its canonical form [ʃak] tends to occur everywhere except before voiced obstruents. French infants could thus hypothesize that one is the assimilated form of the other, without knowing their meaning. This distributional learning mechanism would be available from a very young age. Evidence from artificial language learning studies suggests that young infants can already exploit distributional cues for the purposes of phonological rule learning. In particular, White et al. (2008) showed that 12-month-old American infants can learn that certain consonants alternate with one another, purely on the basis of distributional information.

One final source of information for infants to acquire knowledge of the assimilations in their native language is the presence of partial assimilations. As mentioned earlier, not all assimilations are complete. A significant percentage of assimilations in French and English are only partial (Ellis & Hardcastle, 2002; Snoeren et al., 2006), yielding segments that are ambiguous between two phonetic categories. Toddlers could use such partial assimilations in a bottom-up fashion to adapt to native assimilations. If a partially assimilated segment occurs, it is a reliable indicator that a phonological process has been applied. However, before much emphasis is placed on this learning route, more research is needed to find out whether or not toddlers (and adults) show differences in the processing of complete assimilations, partial assimilations and, indeed, segments that are merely coarticulated.

Regardless of the mechanisms underlying toddlers' acquisition of assimilations or the availability of adequate language-specific information about assimilations in the child input, the current study provides clear evidence that toddlers as young as 3 years old take assimilations into account during word recognition. Furthermore, the contrast in French toddlers' performance with native and non-native assimilations suggests that by this age, toddlers' perceptual sensitivities are tuned to the particular phonological processes prevalent in their native language. Our findings, therefore, provide a spring board toward establishing when and how native assimilations are acquired.

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Appendix A

Table A1 shows the target words used in Experiment 1. They were all used in the same carrier sentences, examples with ''boat'' (final [t]) and ''pen'' (final [n]) are given for the experimental conditions in Table A2.

Table A1
Test Stimuli Used in Experiment 1

Nouns with final *t*	Nouns with final *n*
boat	bin
boot	clown
coat	moon
cot	pen
foot	plane
fruit	spoon
goat	sun
hat	train
plate	
shirt	

Table A2
Examples of Pointing Requests Used in Experiment 1

Noun type	Assimilation	no-assimilation
final [t] (e.g., *boat*)	Can you find the boa[pm]y dear?	Can you find the boa[pr]ight here?
final [n] (e.g., *pen*)	Can you find the pe[mp]lease?	Can you find the pe[md]ear?

Appendix B

Table B1 shows the target words, translations and contexts used in Experiment 2. All pointing request sentences start with *Montre le/la …* (''Show the …'').

Table B1
Test Stimuli Used in Experiment 2

Noun	Assimilation	no-assimilation
boîte [bwat] ''box''	*boî[d] juste ici* (''just here'')	*boî[d] là-devant* (''there in front'')
botte [bɔt] ''boot''	*bo[d] juste ici*	*bo[d] là-devant*
tête [tɛt] ''head''	*tê[d] juste ici*	*tê[d] là-devant*
chaise [ʃɛz] ''chair''	*chai[s] par ici* (''over here'')	*chai[s] là-devant*
singe [sɛ̃ʒ] ''monkey''	*sin[ʃ] par ici*	*sin[ʃ] là-devant*
robe [ʁɔb] ''dress''	*ro[p] qui est là* (''that is there'')	*ro[p] là-devant*
bouche [buʃ] ''mouth''	*bou[ʒ] de Paul* (''of Paul'')	*bou[ʒ] là-bas* (''over there'')
bus [bys] ''bus''	*bu[z] de Paul*	*bu[z] là-bas*
couche [kuʃ] ''diaper''	*cou[ʒ] de Paul*	*cou[ʒ] là-bas*
douche [duʃ] ''shower''	*dou[ʒ] de Paul*	*dou[ʒ] là-bas*
vache [vaʃ] ''cow''	*va[ʒ] de Paul*	*va[ʒ] là-bas*
pouce [pus] ''thumb''	*pou[z] de Paul*	*pou[z] là-bas*

Appendix C

Table C1 shows the target words, translations and contexts used in Experiment 3. All pointing request sentences start with *Montre le/la* … (''Show the …'').

Table C1
Test Stimuli Used in Experiment 3

Noun	Assimilation	No-assimilation
lune [lyn] ''moon''	*lu[m] par ici* (''over here'')	*lu[m] de Paul* (''of Paul'')
clown [klun] ''clown''	*clow[m] par ici*	*klu[m] de Paul*
âne [an] ''donkey''	*a[m] par ici*	*a[m] de Paul*
tête [tɛt] ''head''	*tê[p] mon poussin* (''my chick'')	*tê[p] là-bas* (''over there'')
botte [bɔt] ''boot''	*bo[p] mon poussin*	*bo[p] là-devant* (''there in front'')
boîte [bwat] ''box''	*boî[p] mon poussin*	*boî[p] là-devant*
chaise [ʃɛ̃z] ''chair''	*chai[v] mon poussin*	*chai[v] là-devant*
fraise [fʁɛz] ''strawberry''	*frai[v] mon poussin*	*frai[v] de Paul* (''of Paul'')
pouce [pus] ''thumb''	*pu[f] mon poussin*	*pu[f] là-bas* (''over there'')
brosse [bʁɔs]''brush''	*bro[f] par ici* (''over here'')	*bro[f] là-bas* (''over there'')
bus [bys] ''bus''	*bu[f] par ici*	*bu[f] là-devant* (''there in front'')
tasse [tas] ''cup''	*ta[f] par ici*	*ta[f] là-devant*