Developmental Changes in the Discrimination of Vowel Contrasts in Bilingual Infants

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1. Introduction

While adults selectively perceive sound contrasts that serve to distinguish meaning in their native language (see Strange, 1996, for a review), behavioral studies of speech sound discrimination in young infants have shown that they can initially discriminate many different phonetic contrasts and that this capacity is not constrained to a specific language (Werker, Gilbert, Humphreys & Tees, 1981; Aslin, Pisoni, Hennessy & Percy, 1983; Best, McRoberts & Sithole, 1988). However, a shift from language-general to language-specific discrimination is found during the second semester of life. While this is a well attested phenomenon for consonantal contrasts, for which a decline in sensitivity has been identified around 10-12 months of the age (Werker & Tees, 1984), the developmental changes in the perception of vowel contrasts seem to take place some time earlier, beginning around the age of 6 months. Work done by P. Kuhl and colleagues offered evidence of enhanced generalization around prototypical exemplars of native vowel categories, while discrimination was still preserved for exemplars around non-prototypical vowels in 6-month-old infants, but not at 4 months of age (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992). In a different study, foreign vowel contrasts could be discriminated by 4 months of age, but this pattern of discrimination was already modified by 6 to 8 months of age and inability to discriminate those foreign sounds was clearly observed by the end of the first year of life (Polka & Werker, 1994).

Early sensitivities regarding vowel sounds have been analyzed in different studies. In one of the first works, 1 to 4 month-old English-learning infants were able to distinguish the /a/ - /i/ and /a/- /u/ native-language contrasts with natural exemplars (Trehub, 1973), and also the non-native Polish/French, oral nasal vowel contrast [pa] – [pă] (Trehub, 1976). Moreover, infants 2 to 4 months of age, could discriminate the /a/ - /i/ native contrast using several speakers and pitch variations, thus showing that perceptual constancy for these vowel elements could be easily achieved early in development (Kuhl, 1979). Even more subtle contrasts in the native language have been discriminated by young infants, such as /i/ versus /I/, at 2 months of age, although in a non-categorical manner (Swoboda, Morse, & Leavitt, 1976), and /a/ versus /ɔ/, also very close in the vowel space, at 6 months of age (Kuhl, 1983).

Age related changes in speech sound discrimination abilities have also been obtained in ERP studies. Recent developments in the study of electric brain responses to auditory stimuli have offered evidence in support of a language-specific change in memory traces for vowel sounds, related to the phonemic status that these vowels have in the language of exposure and occurring by the end of the first year of life (Cheour, Ceponiene, Lehtokoski, Luuk, Allik, Alho, & Näätänen, 1998). When electrophysiological measures from 6 and 12 month-old infants are compared, the MMN amplitude observed in older infants is higher for native vowel phonemes and lower for non-native ones, thus reflecting this developmental trend in the building of language-specific sound categories.

Different mechanisms have been hypothesized to account for these language-specific perceptual reorganization processes, from the role of exposure to maintain innately tuned distinctions (Aslin & Pisoni, 1980), to the role of attentional factors to justify declines in early sensitivities (Jusczyk, 1985). Generally speaking, it can be considered that these early accounts could not satisfactorily explain the occurrence of these perceptual modifications (Jusczyk, 1997).

Later proposals have claimed declines in initial sensitivities cannot be explained by exposure factors alone and it has been hypothesized that changes in sound discrimination capacities would reflect infants' transition from a pre-linguistic to a linguistic stage of processing speech. These accounts

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suggest that perception of phonetic information by older infants, as well as adults, can be best accounted for by the phonological status of the distinctions being tested, or what is the same, through word learning (Werker & Pegg, 1992; Best, 1995; Lalonde & Werker, 1995). It has also been suggested that it is probably not words in the adult sense, but "possible words", that might have already been extracted from the speech stream but have not yet been mapped on to specific objects and events, what guides these perceptual reorganization processes by the end of the first year of life (Pegg & Werker, 1997).

A different kind of explanation comes from a framework that emphasizes infants' exploitation of statistical properties of speech. Within this perspective one could identify the perceptual learning model developed by P. Kuhl (Kuhl, 2000), which suggests that the learning process begins with infants' detection of patterns and exploitation of statistical properties in the language, and then, through language experience, initial perceptual biases and universal contouring of the perceptual space give way to a language-specific mapping that alters perception. The Native Language Magnet model clearly reflects this developmental process from language-general to language-specific perceptual biases (Kuhl, 1998). Still within an statistical account, a more recent proposal has been developed which suggests a single mechanism based on infants' sensitivities to the distributional properties of their language (Maye, Werker, & Gerken, 2002). In this work, different discrimination patterns were found according to differences in the statistical distribution of phonetic variation in the materials infants were exposed to, thus suggesting that tracking statistical distribution of speech sounds in the input language might be the relevant factor behind re-organizational processes in the first year of life.

All this work that has just been reviewed addresses the study of perceptual reorganization processes in groups of monolingual infants. It is not till recently that the same kind of questions have begun to be posed in relation to infants acquiring two languages simultaneously. Early and continuous exposure to two different sound systems, with different distributions, frequencies and contrastive values must certainly have some specific consequences on the processes of building native-language phonetic categories and on the establishment of two distinct phonological systems. While some evidence exists regarding young bilingual infants capacity to discriminate between the languages of exposure (i.e. Catalan and Spanish at 4 ½ months of age, as in the work by Bosch & Sebastián-Gallés, 2001), phonetic discrimination abilities and developmental changes in speech sound perception for this population have not been thoroughly described.

Previous research in our laboratory, both with adults and infants, using a Catalan vowel contrast corresponding to the two mid-front vowels /e/ - /ɛ/, has offered interesting data. This is a contrast non-existent in Spanish, a system with a single /e/ vowel category which imperfectly maps on the /e/ Catalan vowel. Early bilingual adults (i.e. first exposed to Spanish and from around age 3 also exposed to Catalan) show problems in perceiving this contrast and their behavior differs from the one observed in Catalan monolingual or Catalan-dominant bilingual population (Bosch, Costa, & Sebastián-Gallés, 1994; Bosch, Costa, & Sebastián-Gallés, 1997; Pallier, Bosch & Sebastián-Gallés, 1997; Sebastián-Gallés & Soto-Faraco, 1999; Bosch, Costa, & Sebastian, 2000; Pallier, Colomé, & Sebastián-Gallés, 2001). What this adult data confirm is that the perceptual reorganization processes and the building of native-language categories takes place across the first year of life and remains rather stable in spite of exposure to a second language, at least for sound categories that show an imperfect match between the two languages in the bilingual situation.

More relevant to our present purposes are data from bilingual infant studies. Results from this research in our laboratory have offered evidence of a U-shaped pattern in Catalan-Spanish bilinguals' capacity to discriminate the two mid-front vowels of Catalan, i.e. /e/ vs. /ɛ/ (Bosch and Sebastián-Gallés, 2003). The pattern obtained indicated that discrimination was available by 4 months of age (a language-general capacity), but evidence of this capacity was no longer observed at 8 months of age. However, 12-month-old bilingual infants were eventually able to reach discrimination for this specific vowel contrast. Different factors were brought into consideration in order to interpret this particular bilingual pattern of results. The capacity to differentiate between the languages of exposure was one of them, but also factors derived from the specific comparison between the two vowel systems (differences in the number of contrastive elements in the repertoire, their frequency in the input and the level of overlap between different categories) were considered to be relevant in interpreting the data.

Last but no least, total amount of exposure to each of the languages in the environment was also considered. As a conclusion, it was hypothesized that phonetic analyses of the bilingual input might result in a shared perceptual space, common to both languages. Moreover, the specific location of those mid-front vowels, almost forming a continuum from /e/ to /ɛ/, with Spanish /e/ falling in-between the two Catalan vowels (Bosch, Costa & Sebastián-Gallés, 2000), and also the higher frequency of Spanish /e/ over the two Catalan vowels (around 30% in Spanish versus 8% in Catalan), could have as a consequence the grouping of them together, forming a single extended category and making discrimination difficult to be reached.

The eventual recovery to perceive the contrast by 12 months of age can be accounted for both by the phonological status explanation and the distributional account. The former would predict that once the infant is able to segment and store possible word forms, the phonetic information would then be gradually transformed into phonological information and it might be linked to language-specific lexical items and possible word-forms that follow the specific phonological constraints of a given language. This process could possibly be started around 8-9 months of age, when infants' sensitivities to language-specific phonotactic constraints are well in place (Friederici & Wessels, 1993; Jusczyk, Luce & Charles Luce, 1994; Sebastián-Gallés & Bosch, 2002) and detailed knowledge about the properties of the segmental or phonetic repertoire for each of the languages of exposure can begin to be built. Preliminary data obtained with French-English bilinguals at 7 ½ months of age (Polka, Sundara, & Blue, 2002) indicates that these infants are able to segment disyllabic words in two rhythmically distinct languages at the same age as their monolingual peers. Presumably, some gains in the knowledge relative to the differential phonology of the languages of exposure might begin to develop from this age on.

From the distributional perspective, a possible explanation would be that infants start building a single category derived from the specific locations of these vowels in the mid-front area, but through continued exposure to these two languages, they would eventually form smaller subcategories within this broader mid-front vowel space, thus reaching discrimination at a later age, if compared with infants from monolingual environments. At present, with the available data, restricted to a single contrast, it is still too early to choose which of the two accounts just mentioned would become the best explanation. In any case, the early capacity to differentiate between the languages of exposure (Bosch & Sebastián-Gallés, 2001; Bosch & Sebastián-Gallés, 1999) does not seem to interfere with any of the above mentioned explanatory hypothesis. Even if some positive evidence of between-language discrimination has already been gathered, there is no indication that the capacity to make this distinction results in the existence of separate files, where language specific information would be stored. So, it is possible that even though languages can be distinguished, phonetic information is not readily differentiated in language-specific files for some time during the second semester of life.

The present research was designed to further analyze the impact of bilingual exposure on the perception of native-sound contrasts and the early building of language-specific contrastive categories in infants from monolingual and bilingual (Spanish-Catalan) environments, by using two different vowel contrasts, one close within the vowel space [/o/ - /u/], and a more distant one [/e/ - /u/], both present in the languages of exposure. The selected ages where 4 and 8 months, as the aim of this study was to have a deeper insight on the generality of the pattern that had already been obtained with the mid-front vowels (Bosch & Sebastián-Gallés, 2003). While it was expected to find discrimination of both contrasts at 4 months of age, two different outcomes were predicted at 8 months of age. If proximity in a relatively crowded vowel space (as it is generally the case in bilingual exposure) is a relevant factor, then only the more distant contrast would be discriminated by 8 months of age. However, if the non-discrimination of the mid-front vowels was merely the consequence of the partial overlapping of these categories when both languages are compared, then, the close [/o/ - /u/] contrast should also be discriminated, as the two sounds are contrastive in both of the languages under study, even if their prototypical values might not be exactly the same (Echeverría, 2002, found higher values for extreme Catalan vowels than for Spanish ones).

Two series of experiments, with the same design and discrimination procedure, were run. First one was addressed to analyze the close contrast, [/o/ - /u/], common to both languages and the second one to analyze the discrimination of the more distant vowels in the perceptual space.

2. First series of experiments on the [/o/ - /u/] contrast

2.1 Stimuli

The stimuli were similar in nature to those used in the experiments previously designed to analyze the capacity to discriminate the mid-front vowels in bilingual infants (Bosch & Sebastián-Gallés, 2003). Natural exemplars of the target [dodi] - [dudi] pseudo-words, always stressed on the first syllable, were recorded with six different female speakers using a motherese style. Eighteen stimuli were finally selected from the recordings which were adequately classified as exemplars belonging to one of these two phonetic categories by adult competent native speakers of both Catalan and Spanish. Thus, differences in length, syllable duration and pitch contour were deliberately searched in order to create a variable set of tokens that differed in acoustic terms but could be grouped together from a phonetic category perspective. As in the previous experiment on mid-front vowels, one of the main points here was to assess young infants' discrimination based on perceptual normalization of these highly variable word-shaped stimuli (token plus talker variability).

From this selected material, two familiarization sets were built (half of the infants were familiarized to /o/ and the other half to /u/ stimuli, either [dodi] or [dudi] tokens). Thus, twelve tokens of each category were selected for the familiarization phase and the remaining six in each category were used in the test phase (all infants had exactly the same twelve tokens in the test phase –six same and six switch-, regardless of the sound category they had had in their familiarization phase).

2.2 Procedure and apparatus

A modified version of the familiarization-preference procedure (Jusczyk & Aslin, 1995) was used to assess discrimination, as it had been successfully used in our laboratory to test discrimination between languages (Bosch & Sebastián-Gallés, 2001). This paradigm includes a two minutes' familiarization phase, with presentation of the auditory stimuli contingent on infants' looking behavior, followed by a test phase in which listening times to contrastive materials are monitored. Differential attention time to similar versus novel materials in the test phase are interpreted as indicative of discrimination. In the present experiment, a novelty reaction in the test phase was expected, that is, after being familiarized with tokens having a specific vowel sound on the first syllable, if discrimination is reached, infants should prefer to listen to stimuli with a different vowel sound in the test phase (switch test trials).

The testing took place in a single session which lasted less than five minutes. In the familiarization phase infants were exposed to twelve different tokens of the target stimuli (half of the infants were familiarized with [dodi] and the other half with [dudi]) until they reached criterion, that is, until they had accumulated 2 minutes of sustained attention to this material (1 minute to each of the two lists that contained 6 tokens of the same vowel category repeated twice). Two sets of familiarization tokens from the same vowel category were presented on alternating trials from the left and right loudspeakers. On each trial the order of presentation of the six tokens (twice repeated) was randomized for every infant and the side of the presentation for each list was also randomly assigned so that no loudspeaker could be associated to a specific list of tokens. Maximum length for each trial was 25 seconds which meant that infants needed at least 6 familiarization trials to reach criterion and proceed to the test phase. In this phase, there were four test trials with the same structure and duration as the familiarization ones, two test trials in which new tokens of the same vowel used in the familiarization phase were presented (same trials) and other two in which new tokens of the contrastive vowel could be heard (switch trials). The sequence of trial presentation in the test phase was quasi random: it could begin with either a same or a switch trial, but no two same or two switch trials could be the first two trials of the test phase, they had to belong to different categories.

A trial started with an image on the center monitor to capture infant's attention; as soon as she began to look at it, this image disappeared and a different image appeared on one of the two side monitors. When the infant was looking in that direction, the presentation of the test stimuli began and continued until its completion or until the infant ceased to look for more than two consecutive seconds.

Shorter non-looking times did not determine the end of the trial but were subtracted from the total attention time of that trial.

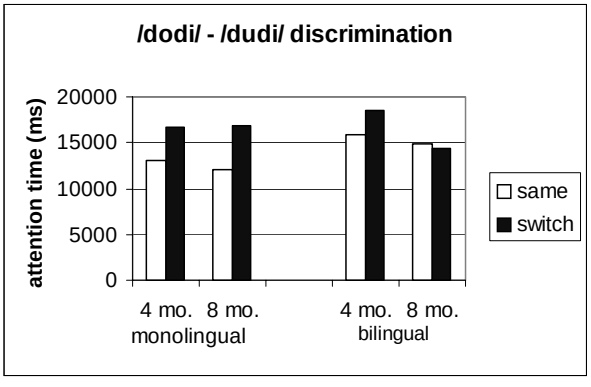
Testing took place in a 3-sided (1.6 m) test booth within a sound-attenuating laboratory room, next to a control room from where the experiment was run and infants' looking behavior was monitored and continuously recorded. In the test booth, the infant was seated on a special chair (the 4-month-old infants) or on her mother's lap (the 8-month-olds), facing three monitors in which simple but colorful animated images were presented. Two loudspeakers, from which the audio material was presented, were hidden below the two lateral monitors. An experimenter was in an adjacent room, totally unaware of the materials presented to the infant, monitoring infants' looking behavior and recording the whole testing session. The video recordings obtained were used later to assess reliability of the measures that had been stored.

2.3 Participants

A total of forty-eight infants participated in this experiment. All of them were healthy, full-term babies with no history of ear infections according to parents' report. They were divided into two age groups, 4- and 8-month-olds, respectively, and further subdivided into two groups according to their linguistic environment (monolingual and bilingual families). A detailed questionnaire (as in Bosch & Sebastián-Gallés, 2001) was used to establish the language/s spoken by the parents and other close relatives and to reach an estimate of the hours of daily exposure to the language/s, so that infants could then be correctly classified as monolingual or bilingual. To be included in the monolingual group, the percentage of daily exposure to the family language had to be at least 80% (with, if any, sporadic and indirect exposure to the other language not spoken at home). Infants in the bilingual group were those that had a balanced distribution of daily exposure to both Catalan and Spanish, ranging from 50%-50% to 65%-35%. Infants who belonged to a bilingual family but who did not have a daily exposure to both languages in their environment were not recruited.

2.4 Results

A different pattern of results was obtained for this [/o/ - /u/] contrast depending on the type of linguistic environment. By 4 months of age, discrimination could be observed in both groups (monolingual and bilingual), as they had significantly longer attention times to switch test trials. However, a differential pattern was obtained at 8 months of age in that only the monolingual group gave evidence of discrimination.



These results mirror the ones obtained in our previous work with the mid-front Catalan vowels (Bosch & Sebastián-Gallés, 2003), but in this case the contrast is one that exists in both languages. Even if one considers that the prototypical values of these vowels slightly differ in each of the languages, the fact that they are contrastive should facilitate discrimination. However, if one considers

the vowel repertoires in both languages, Catalan having two mid-back vowels in this area while Spanish has only one, which is more frequent in the language than the Catalan equivalent, then it can be argued that perhaps the discrimination problems that have been observed are related to these specific distributional factors. Again, in this rather crowded area of the vowel space, bilinguals' input offers more variation which can be best described as a unimodal distribution, thus favoring the building of a single macro-category (back, rounded vowels), at least initially.

In order to further analyze this issue, two additional experiments were run with 8-month-old infants, using simplified material for this [/o/ - /u/] contrast. First, talker variability was reduced, from six to two speakers. Second, tokens were reduced to a monolsyllabic element, [/do/ - /du/], and a single speaker was used.

3. Additional experiments on the [/o/ - /u/] contrast

3.1 Stimuli

For the first additional experiment, eighteen stimuli for each category were selected from the previous recordings, but this time only two speakers were used. As described before, from this selected material, two familiarization sets were built (half of the infants were familiarized to /o/ and the other half to /u/ stimuli, either [dodi] or [dudi] tokens). Thus, twelve tokens of each category were selected for the familiarization phase (six from each of the speakers) and the remaining six in each category were used in the test phase (all infants had exactly the same twelve tokens in the test phase –six same and six switch-, regardless of the sound category they had had in their familiarization phase).

For the second additional experiment, eighteen stimuli for each category were selected from a single speaker and the second syllable was eliminated, so that [do] vs. [du] stimuli were obtained. The target tokens were the most distant ones that could be selected for these two categories, so that discrimination could be maximally facilitated in this experiment.

3.2 Procedure and apparatus

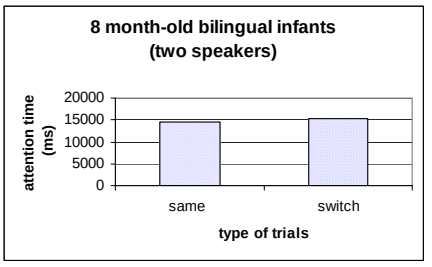
The same as in the previous series of experiments.

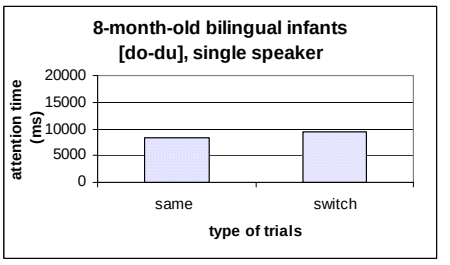
3.3 Participants

Two groups of twelve 8-month-old bilingual infants participated in these experiments. All of them were healthy, full-term babies with no history of ear infections according to parents' report. The bilingual status of their families was assessed through the same questionnaire mentioned before (as in Bosch & Sebastián-Gallés, 2001) and the same criteria were used: only those infants that had a balanced distribution of daily exposure to both Catalan and Spanish, ranging from 50%-50% to 65%-35% were recruited.

3.4 Results

Results from these two additional experiments on the [/o/ - /u/] contrast confirm the inability to reach discrimination in 8-month-old infants from Catalan-Spanish bilingual environments, even when complexity of the material has been largely reduced, first by using just two speakers (instead of six) and also by using a single speaker and monosyllabic tokens.





These results suggest that the reduced discrimination ability observed at the age of 8 months in this bilingual population is a fairly robust effect that extends beyond a specific area in the vowel space and that seems to manifest even in the easiest condition, when the material in the test would favor a differentiation based on an acoustic rather than on a phonetic basis.

4. Series of experiments on the [/e/ - /u/] contrast

A second series of experiments had also been planned to test the capacity to discriminate a more distant contrast in the vowel space. The mid-front vowel /e/ (present both in Catalan and Spanish, although with slightly different prototypical values) and the high-back rounded /u/ vowel also present in both languages were selected. If proximity, and possible crowdedness in the vowel space are determinant factors that reduce discriminability between certain contrasts, the target vowels in this case, because of their acoustic distance, should not pose a problem for the bilingual population.

4.1 Stimuli

The [dudi] stimuli for this experiment were the same as the ones described in 2.1, and the [dedi] tokens were exactly the same that had been used in a previous experiment with mid-front vowels (Bosch and Sebastián-Gallés, 2003).

4.2 Procedure and apparatus

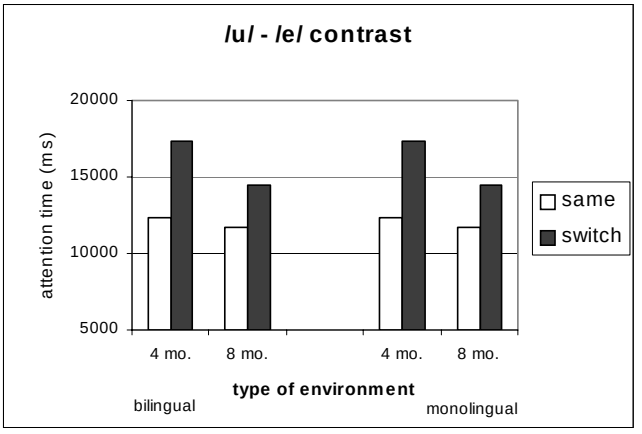
The same as in the previous series of experiments.

4.3 Participants

A total of forty-eight infants participated in this experiment. All of them were healthy, full-term babies with no history of ear infections according to parents' report. They were divided into two age groups, 4- and 8-month-olds, respectively, and further subdivided into two groups according to their linguistic environment (monolingual and bilingual families). The monolingual or bilingual status of their families was assessed through the same questionnaire mentioned before (as in Bosch & Sebastián-Gallés, 2001) and the same criteria were used for classification.

3.4 Results

Results for this contrast indicate that discrimination is reached at both age levels and for both types of linguistic environments. Significantly longer attention times to switch trials were obtained both for the monolingual and the bilingual groups of infants, thus suggesting that this contrast can be easily perceived.



5. Conclusions

Results from this series of experiments on two different vowel contrasts, a close and a distant one in the vowel space, have shed some light on a developmental pattern of responses previously found in infants from bilingual environments. In the first series of experiments a decrease in sensitivity to perceive the [dodi - dudi] contrast at 8 months of age, only in the bilingual group, suggests that the U-shaped pattern previously observed for the mid-front Catalan vowels would also be obtained for these back, rounded vowels, common to both languages of exposure (preliminary data from a group of 12 month-old bilingual infants show evidence of discrimination at this later age). Results from the additional experiments on this same contrast give robustness to this specific pattern, as even when variation in the material was significantly simplified (by reducing talker variability and length of the stimuli), infants showed no evidence of discrimination. Finally, the last series of experiments targeted a more distant contrast for which the reduced sensitivity at 8 months of age was not obtained, thus suggesting a limit in the generality of this specific pattern.

Taken together these results indicate that accounts based on exposure, as the single factor that maintains initial discrimination capacities, cannot be easily applied to the bilingual situation. Instead, sensitivity to distributional properties and a mechanism that extracts statistical information from the languages of exposure seem a better approach to explain the response pattern observed in bilinguals. Data up to now, suggest that there might be an initial building of wider categories that group together close sounds from both languages that share common areas in the vowel space. However, the eventual discrimination of these contrasts that has been observed requires the identification of a mechanism that would trigger the formation of these language-specific categories. Future research should address this crucial issue.

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