Are faster habituators better discriminators:

The decrement of habituation as a predictor of speech sound discrimination

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Utrecht University
Language- and Culture Studies

Marjoleine Meijs
5687527

Supervisor: Maartje de Klerk
Second reader: Frank Wijnen

Abstract

The main goal of this study was to investigate whether there is a relation between the habituation decrement, i.e. the percentage of decrease in listening time during the habituation phase, and the effect of condition measured during test phase. Based on Sokolov's model (1963), it was expected that the higher the percentage of decrease of habituation, the bigger the effect of condition measured during test. Data of 38 6-month-olds were analyzed from de Klerk, de Bree, Kerkhoff & Wijnen (under revision), who used the hybrid visual fixation paradigm (designed by Houston, Horn, Qi, Ting & Gao, 2007) to assess speech sound discrimination skills. Our results showed no correlation between the percentage of decrease of habituation and the absolute nor the relative mean difference between listening time to alternating and non-alternating trials. This is not directly in line with the expectations based on the theory and therefore needs further research.

The use of listening time as the dependent variable is the most common behavioral technique used to study infants' abilities (Aslin, 2007), such as speech perception skills. Much of our current knowledge of infants' development of speech perception is based on a methodology using a habituation paradigm. In habituation paradigms, infants are habituated on a stimulus, or a set of stimuli, and then tested on the ability to distinguish those stimuli from new stimuli during the test phase (Aslin, 2007). This method can be used for habituation studies gaining group result, for example, we know from earlier studies using this method that newborns start out life as language-general or universal listeners and become language-specific listeners in the first year of life (e.g. Werker & Tees, 1984; Kuhl, Williams, Lacerda, Stevens & Lindblom, 1992). But the problem is that individual differences sometimes cause null-results for the group result (Houston-Price & Nakai, 2004), which makes interpreting the results of experiments using a habituation difficult.

There are different theoretical approaches for explaining infant habituation (Jeffrey, 1968; Groves & Thompson, 1970), where the comparator model (Sokolov, 1963) is the most popular (Colombo & Mitchell, 2009). Sokolov's comparator model (Sokolov, 1963) is based on the orienting reflex. The orienting reflex is proposed to be a cluster of responses elicited by the detection of a non-threatening, moderately intense novel or unexpected stimulus. These responses contain suppressed heart rate, respiration, skin resistance, pupil dilation and reduced motor activity, including the fixing of sensory receptors at or toward the source or location of the stimulus. Sokolov (1963) reasoned that if a new stimulus is provided, infants would show a bigger orienting reflex than with stimuli that were already shown before. The reasoning behind this is that the infant has formed an internal representation of the previous stimuli and therefore the orienting reflex is less intense. With repeated presentation and increased familiarity with the stimulus, the orienting reflex can be said to be habituated: the reflex is less intense because the stimulus is recognized. Habituation studies are built upon this idea: at the beginning of the habituation phase looking times are long and these will decrease as the internal representation becomes stronger. Recovery of looking time to the new stimulus will occur when the new, contrasting, stimulus is detected by the infant, hence, if the infant perceives the difference between the old and new stimuli (e.g. Colombo & Mitchell, 2009; Houston-Price & Nakai, 2004).

In habituation paradigms, infants are habituated on a stimulus, or a set of stimuli, and then tested on the ability to distinguish those stimuli from one or more new stimuli (Aslin, 2007). The use of looking/listening time as the dependent variable is the most common behavioral technique used to study infant behavior (Aslin, 2007). The most commonly used habituation paradigm since Horowitz, Culp, Paden, Bhana & Self (1972) and Horowitz, Paden, Bhana & Self (1972) is an infant-controlled procedure, i.e. the trial length is depending on the looking time of the infant instead of a fixed trial length, which had the problem of a high drop-out rate (Horowitz, Culp et al, 1972). A second characteristic of habituation studies is the habituation criterion. The habituation criterion is used to be able to compare different participants and different studies to each other, moreover, it is assumed that infants are at the same level of processing when they meet the criterion (Colombo & Mitchell, 2009). Traditionally researchers used a 50% decline in mean looking time across three successive trials compared to the initial three trials (Aslin, 2007), but there have been various remarks about this criterion (Dannemiller, 1984; Ashmead & Davis, 1996; Gilmore & Thomas 2002 & Thomas & Gilmore, 2004). For instance, Ashmead & Davis (1996) suggested to use a 40% decrement criterion instead of a 50% decrement which was used before. As a result, the use of a 65% criterion (a 35% decrement) has been increased, for example by Werker, Cohen, Lloyd, Castola & Stager (1998), Pater, Stager & Werker (2004) and Liu & Kager (2014).

Another suggestion, from Dannemiller (1984) was that possibly a lower false alarm rate would be expected from a less strict criterion, for example, 40% decrement instead of 50% decrement. The false alarm rate is defined as the probability that the habituation criterion will be reached when the infant actually is not habituated yet (Dannemiller, 1984). If infants met the habituation criterion without being habituated, they will probably look longer to old than to new trials during test.

This latter case can arise when an infant shows a great deal of variability in his fixation times over trials (for a discussion, see Horowitz, Paden, Bhana, & Self, 1972). This can, for example, happen thanks to internal and external factors, such as an unexpected noise or hunger (De Barbaro, Chiba & Deák, 2011), that make the infant distracted. Besides, looking time reflects both active processing and “blank stares” (Aslin, 2007), so it is also possible that infants did not encode the stimuli completely but were just staring.

Habituation paradigms rely on a global measure of looking time, which is an indirect measure of processing: looking time reflects both active processing and “blank stares” (Aslin, 2007), hence, the extent to which infants are actively processing the stimuli varies within a look (Colombo & Mitchell, 2009). However, it is assumed that the infant has an internal representation of the habituation stimuli at the end of the habituation phase (Sokolov, 1963), however, this is not necessarily the case (Hunter & Ames, 1988; Houston-Price & Nakai, 2004). It has been claimed that the 50% decrement criterion may guarantee that only a bare majority of infants truly habituate (Colombo & Mitchell, 2009; Gilmore & Thomas, 2002). Another note raised by Thomas & Gilmore (2004) is the probability of misclassifying infants who are not truly habituated to unacceptably high levels. This leads to the assumption that some infants having longer listening times to old stimuli than to new stimuli (Colombo & Mitchell, 2009). These assumptions and notes combined with the fact that there are quite some differences between studies in habituation criterion used, need to be looked at critically. Is it possible to say something about the mean difference in listening time to novel stimuli and listening time to stimuli where the participant is already habituated on based on the percentage of habituation decrement?

This study is based on the theory of Sokolov (1963), that says infants look longer to new stimuli than to familiar stimuli. Habituation studies are built upon this assumption, taking looking time as the dependent variable, while looking time is an indirect measure (Surtees, Butterfill & Apperly, 2012). This study investigates whether the listening time to old and new trials has a relation with the percentage of habituation decrement. This has two sides: a magnitude and a direction.

Present study

For this research, I used part of the data from the study of de Klerk, de Bree, Kerkhoff & Wijnen (under revision) about native vowel discrimination in Dutch-learning 6-, 8- and 10-month old infants. It was assessed whether they could discriminate a native vowel contrast, /a:/ and /e:/, embedded in pseudowords *faap* (/fa:p/) and *feep* (/fe:p/). The habituation paradigm used for this study was designed by Houston, Horn, Qi, Ting and Gao (2007) and contained a habituation phase in which repetitions of one vowel type were presented (e.g. /fa:p/) and a test phase in which both vowel types were presented in alternating trials (e.g. /fe:p/ - /fa:p/) and non-alternating trials (e.g. /fa:p/ - /fa:p/). For the current study, I only used the data of the 6-month-old infants, because this age group showed the highest variability in mean listening time to both test trials (de Klerk et al., under revision).

Houston et al. (2007) used a 50% decrement habituation criterion. Dannemiller (1984) and Ashmead & Davis (1996) suggest a 40% decrement criterion, because a less strict criterion would possibly result in a lower false alarm rate. De Klerk et al. used a 35% decrement habituation criterion, just like other recent studies (by Werker, Cohen, Lloyd, Castola & Stager, 1998; Pater, Stager & Werker, 2004; Liu & Kager, 2014). On behalf of the comparator model of Sokolov (1963), infants should have a qualitative better internal representation if their listening time drop is higher (and thus show a bigger decrement of habituation percentage) which should result in a bigger mean difference between listening time to alternating trials and non-alternating trials. If indeed there is a relation between those two variables, the difference between a 50% decrease in listening time and a 35% decrease in listening time to habituation trials can be an important difference. To investigate this, the main research question in this study will be: *Is there a relation between the percentage of decrease in listening time to habituation trials and the mean listening time difference between alternating trials (old) and non-alternating (new) trials?* The expectation is that there is a relation: the bigger the decrease in listening time to the habituation trials, and thus the assumed stronger internal representation, the bigger the mean difference between listening time to alternating trials and non-alternating trials.

Method

The data used in this study is obtained from de Klerk et al. (under revision). First, a short summary of the method used for data collection by de Klerk et al. (under revision) will be presented, then the method of this study will be explained.

Participants

Sixty 6-months-old infants were tested on the native contrast, with a dropout rate of 36,7%, as can be seen in Table 1. 38 infants where included for data analysis and these same data were used in the present study. Infants were recruited via the municipality of Utrecht and were only selected for participation if they had monolingual Dutch caretakers, average gestational age (37-43 weeks) at birth, average birth weight (2500-5000 grams) no complications during the pregnancy or delivery, no history of know hearing loss or reduced vision and no reported neurological problems.

Table 1

Number of Participants, Mean Age, Age Range, and Dropout Rates for the Age Group of 6-month-olds.

Age range	Age (days)	Infants Tested	Infants Included
month.day	*M (SD)*	*N*	*N (female)*
6.1-6.30	203 (8.4)	60	38 (18)

Note. The Table is adjusted from *Lost and found: Decline and reemergence of non-native vowel discrimination in the first year of life* (p. 8) from de Klerk et al. (under revision).

Stimuli

On a TV-screen, visual stimuli were shown (see Figure 1): 25 cartoon pictures alternated each other, always three at a time, during pre- and posttest. During habituation and test, six pictures of female faces alternated each other, in pseudorandomized order. In between habituation trials, a movie of a laughing baby was shown as the attention getter. In between test trials, a toddler going down a slide served as the attention getter.

Figure 1. Pictures used during pre- and posttest (picture 1); during habituation and test (picture 2) and the attention grabber used during habituation (picture 3) and test (picture 4). Adjusted from *Lost and found: Decline and reemergence of non-native vowel discrimination in the first year of life* (p. 9) from de Klerk et al. (under revision).

Underneath the TV-screen, behind the canvas, the loudspeaker was placed. During pre- and posttest, the auditory stimuli were beep sounds. During habituation a minimum of six and a maximum of twelve trials of one of the two pseudowords *faap* (/fa:p/) or *feep* (/fe:p/) were presented, depending on the number of trials needed for habituation. During test phase twelve trials were presented: number 1 or 2, 5, 8 and 12 were alternating, the others were non-alternating to the habituation trials. Figure 2 shows a schematic of the procedure.

Pretest	Habituation Phase	Test Phase	Posttest
Beep sounds	Trial 1 /fa:p/ (T1.S1)	Trial 1 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	Beep sounds
330 Hz	Trial 2 /fa:p/ (T1.S3)	**Trial 2 /fe:p/-/fa:p/ (T1.S1 – T1.S1)**	330 Hz
250 ms	Trial 3 /fa:p/ (T1.S2)	Trial 3 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	250 ms
ISI 1000 ms	Trial 4 /fa:p/ (T1.S4)	Trial 4 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	ISI 1000 ms
	Trial 5 /fa:p/ (T1.S3)	**Trial 5 /fe:p/-/fa:p/ (T1.S1 – T1.S1)**	
	Trial 6 /fa:p/ (T1.S2)	Trial 6 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	
	Trial 7 /fa:p/ (T1.S4)	Trial 7 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	
	Trial 8 /fa:p/ (T1.S1)	**Trial 8 /fe:p/-/fa:p/ (T1.S1 – T1.S1)**	
	Trial 9 /fa:p/ (T1.S1)	Trial 9 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	
	Trial 10 /fa:p/ (T1.S2)	Trial 10 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	
	Trial 11 /fa:p/ (T1.S4)	Trial 11 /fa:p/-/fa:p/ (T2.S1 – T1.S1)	
	Trial 12 /fa:p/ (T1.S3)	**Trial 12 /fe:p/-/fa:p/ (T1.S1 – T1.S1)**	

Note. In this example, the first test trial is non-alternating and thus the second is alternating. The remaining three alternating trials have a fixed trial number, namely the 5th, 8th and 12th trial. Alternating trials are printed in **bold**. In the habituation phase, speakers are presented in randomized order per block of 4 trials. Token is abbreviated as 'T' and Speaker as 'S'.

Figure 2. Schematic of the experimental procedure. Adjusted from *Lost and found: Decline and reemergence of non-native vowel discrimination in the first year of life* (p. 9) from de Klerk et al. (under revision).

Procedure

Caretakers consented to participate during their visit to the lab. Infants sat on their caretaker's lap in a three-walled white canvas test booth with a white canvas ceiling. The room was sound-attenuated. The experimenter explained the experimental procedure and told the caretaker that 1) they would be videotaped, 2) they would have to wear headphones playing masking music, 3) the experimenter could stop the experiment at any time, and 4) they were not allowed to interfere with the experiment nor to move their infant unnecessarily but that they were allowed to soothe their child nonverbally when necessary.

Experiments were monitored and recorded through a video camera, placed underneath the TV-screen. The data were recorded online, by pressing buttons on a button-box. For technical or other details, such as how the stimuli were recorded, see de Klerk et al. (under revision).

De Klerk et al. (under revision) used a 65% (35% decrement) habituation criterion for their study. They chose this criterion because this criterion allows for tracing a decrease in attention without introducing a risk that infants tune out entirely. If infant tune out entirely, unwanted data reduction would be the result. Several other studies assessing speech sounds discrimination abilities of young infants used the 65% habituation criterion before (e.g. Werker, Cohen, Lloyd, Castola & Stager, 1998; Pater, Stager & Werker, 2004; and Liu & Kager, 2014).

Data analysis

The data were analyzed using SPSS statistics, version 24.

To answer the question whether the percentage of habituation decrement is a good predictor of the mean difference between listening time to old trials and new trials, three analyses were conducted. The first two analyses investigated whether a correlation could be found wit 1) the relative and 2) the absolute values of the mean listening time difference between old and new trials correlation. The first correlation analysis will shed light on the question whether faster habituators have a stronger preference for new trials. If faster habituators have a stronger internal representation of the habituation stimulus then the expectation is that these infants will listen, on average, longer to the new (alternating) trials. The second correlation will investigate whether the percentage of decrement is correlated to the magnitude of the mean difference, so that is about the magnitude of the difference, independently of the direction.

As mentioned before, some studies use a habituation criterion of 35% decrement and some use a criterion of 50% decrement. In this study, the 35% criterion was used. But there was a numerous group of infants who reached the 50% decrement. To see where there was a significant difference between the group of infants who showed a 50% decrement or more and the group of infants who showed a decrement between 35% and 49%, the dataset was divided into two groups.

Results

Data screening

The mean differences between listening time to alternating trials and non-alternating trials were, as can be seen in Figure 3, not normally distributed (skewness = -1.271, kurtosis 1.617). The negative values made a log transformation not possible. Therefore, non-parametric correlations were conducted. The percentages of decrease of habituation were normally distributed (skewness = -.234, kurtosis = -.931), as can be seen in Figure 4.

Normal Q-Q plots of mean differences between listening times to alternating and non-alternating trials

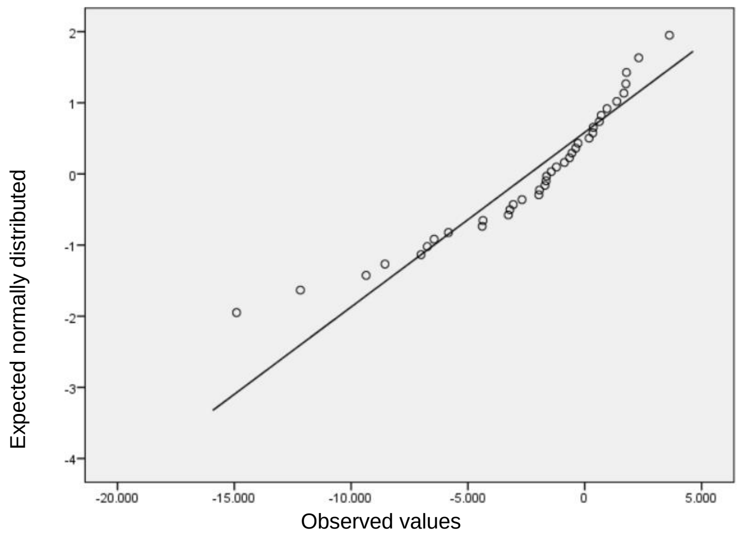

Figure 3. Normal Q-Q plots of mean differences between listening times to alternating and non-alternating trials.

Normal Q-Q plots of percentage of decrease of habituation

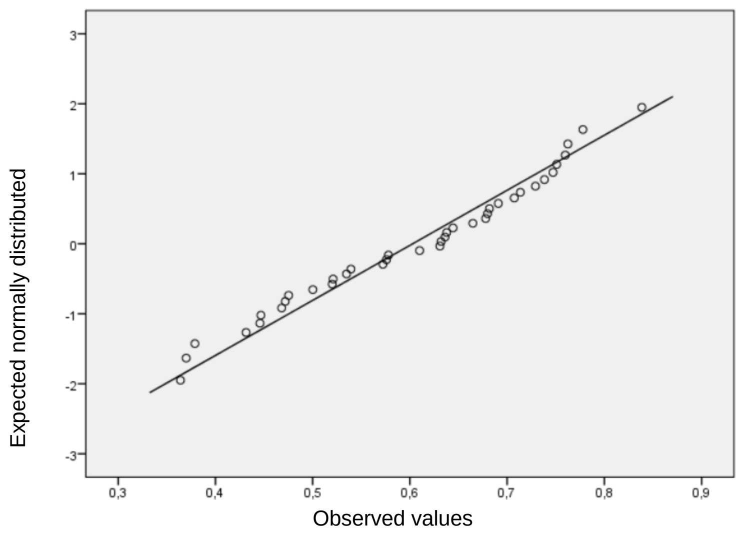

Figure 4. Normal Q-Q plots of percentage of decrease of habituation.

In Table 2 the means and standard deviations of both the percentage of decrease of habituation listening time and the mean listening times differences between alternating and non-alternating listening time are presented.

Table 2
Means Percentage of Decrease of Habituation and Mean Listening Time (s) to Alternating and Non-Alternating Trials.

Age	Habituation Decrement	Alternating Trials	Non-Alternating Trials
	M (*SD*)	*M* (*SD*)	*M* (*SD*)
6 months	60,3 (12,7)	10365 (5448)	7981 (3132)

The correlation between the mean difference between alternating and non-alternating listening time and the percentage of decrease of habituation was not significant, $r = .032$, $p = .424$. There is no correlation found between the mean difference between alternating and non-alternating listening time and the percentage of decrease of habituation. For the second analysis a Spearman's correlation was conducted between the *absolute* mean difference between alternating and non-alternating listening time and the percentage of decrease of habituation. Also this correlation was not significant, $r = .121$, $p = .235$. Both correlation analyses show no relation between the mean difference between alternating and non-alternating listening time and the percentage of decrease of habituation.

A regression analysis was run to investigate whether the percentage of decrease of listening time to habituation trials is a good predictor of the magnitude of the mean difference in looking time listening time to alternating trials and non-alternating trials. The singular linear regression analysis showed no significant regression equation, $F(1, 36) = .171$, $p = .681$, with an R^2 of *.005*. This means that based on these findings, the percentage of decrease of habituation is not a good predictor of the mean listening time differences between alternating and non-alternating trials.

Finally, the dataset was divided into two groups. One group represented infants that had a decrease of habituation of 50% or more and the other group with a decrease of habituation of between 35% and 50%. In Table 3 the means and standard deviations for both groups are presented. There were nine participants in the 35%-50% group, from which 4 (44,4%) looked longer to the non-alternating trials, and 29 in the 50%+ group, from which 8 (27,6%) looked longer to the non-alternating trials. For both groups the correlation and the simple regression analysis were conducted. Both groups didn't show a relation either, where the group 35%-50% showed the correlation $r = .124, p = .751$ and the regression $F(1, 7) = .109, p = .751$, with an R^2 of *.015* and the 50%+-group showed the correlation $r = -.134, p = .487$ and the regression $F(1, 27) = .496, p = .487$, with an R^2 of *.018.* These findings are as well in line with the findings mentioned above: the percentage of decrease of habituation is not a good predictor of the mean difference between alternating and non-alternating listening times.

Table 3
Mean Decrease of Habituation for Group 1 and 2

Percentage of Decrease			
Group 1		Group 2	
M (SD)	*N*	*M (SD)*	*N*
42,8 (4,5)	9	65,7 (8,9)	29

Note. Group 1 represents the group of infants who showed a decrement between 35% and 50% and group 2 represents the infants who showed a 50% decrement or more.

All the findings point towards the same direction: the percentage of decrease of habituation is not a good predictor of the mean listening time difference between alternating and non-alternating trials.

Discussion and Conclusion

The main goal of this study was to investigate whether there is a relation between the habituation decrement, i.e. the percentage of decrease in listening time during the habituation phase, and the effect of condition measured during test phase. To obtain this goal, a dataset of 38 six-month-olds was used. The theory of Sokolov (1963) predicts that when infants hear familiar stimuli, their attention, measured in looking time, will be shorter then when they hear something new, because there has been formed an internal representation of the familiar stimuli in the brains. So the findings are not in line with Sokolov's theory. The expectation was that the higher the percentage of decrease of habituation, the bigger the mean difference between mean listening times to alternating and non-alternating trials.

However, this is not what we saw in the results. There was no correlation found between the *relative* mean listening time differences between alternating and non-alternating trials and the percentage of decrease of habituation. Neither there is a correlation between the *absolute* mean difference between alternating and non-alternating listening time and the percentage of decrease of habituation. Neither there were differences found between the group of infants that had a decrease of habituation of 50% or more and the other group with a decrease of habituation of between 35% and 50%.

These results indicate that there is no clear correlation between the mean difference between alternating and non-alternating listening time and the percentage of decrease of habituation. Adjacent to this, there is no correlation between percentage of decrease of habituation and the absolute mean difference between alternating and non-alternating listening time either, which would have meant the exact opposite of the prediction. The theory of Sokolov (1963) predicts that when infants hear familiar stimuli, their attention, measured in looking time, will be shorter then when they hear something new, because there has been formed an internal representation of the familiar stimuli in the brains. So the findings are not in line with Sokolov's theory.

Based on the results of this study, there are no correlations between the percentage of decrease of habituation and the mean difference in listening time to familiar and non-familiar stimuli. There are no correlations in the total dataset and neither in the group of participants that met the habitation criterion of 50% decrease nor in the group of participants that met the 35% criterion but not the 50% criterion. Neither are there differences found between the group that met the criterion of 50% and the group that met the 35% but not the 50% criterion. This is interesting, because this would suggest there is, for this aspect, no difference between using the 35% or the 50%. This applies to this study, but could potentially count for future, similar studies as well.

Before the 35% decrease criterion with a three-trial window was accepted, a 50% decrease criterion with a two-trial window was the most used method in infant habituation studies (Ashmead & Davis, 1996; Aslin, 2007; Houston et al., 2007). It might be an idea to combine these methods and make it a 35% decrease criterion with a two-trial window, because the three-trial window makes that the infants can be already habituated after three, four or five trials, but it is only possible to habituate after six. A two-trial window is a minimum, because if only single trials will be taken into account, the internal and external factors, such as an unexpected noise (De Barbaro, Chiba & Deák, 2011) have relatively an increased and too high effect. For example, if the caretaker sneezes, the looking time of the infant might be very short because it looks to their caretaker.

Based on this study the suggestion is made that the percentage of decrease of habituation is not a good predictor of the mean difference between alternating and non-alternating listening times. Besides, the suggestion is made that it does not matter for infant studies using a habituation paradigm if a 50% habituation criterion or a 65% habituation criterion is used for the mean difference in listening time to alternating and to non-alternating trials.

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