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Bilingual attentional control: Evidence from the Partial Repetition Cost paradigm

Grace deMeurisse and Edith Kaan

University of Florida, Gainesville, FL, USA

Research Article

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Corresponding Author:
Edith Kaan; E-mail: kaan@ufl.edu

Abstract

The effects of bilingual language experience on cognitive control are still debated. A recent proposal is that being bilingual enhances attentional control. This is based on studies showing smaller effects of the nature of the preceding trial on the current trial in bilinguals (Grundy et al., 2017). However, performance on such tasks can also be accounted for by lower-level processes such as the binding and unbinding of stimulus and response features. The current study used a Partial Repetition Cost paradigm to explicitly test whether language experience can affect such processes. Results showed that bi- and monolinguals did not differ in their responses when the stimulus features were task-relevant. However, the bilinguals showed smaller partial repetition costs when the features were task-irrelevant. These findings suggest that language experience does not affect lower-level processes, and supports the view that bilinguals exhibit enhanced attentional disengagement.

1. Introduction

People differ greatly in their language experience and use. A person who speaks two or more languages fluently and on a regular basis differs from a person who speaks and understands only one language. The first person will need to select the language to be used, inhibit the language not in use (e.g., Kroll et al., 2012), switch between languages, and continuously monitor the context and interlocutors to see which language is appropriate. Many studies have tested the hypothesis that bilingualism influences domain-general cognitive control processes such as inhibition and switching (Bialystok, 2006; Bialystok et al., 2005; Chung-Fat-Yim et al., 2019; Costa et al., 2009). Results from these studies point to effects of language experience on cognitive control, but findings have been inconsistent. This inconsistency has led to a fierce debate about the existence of a "bilingual advantage" and the replicability of the effects (Paap & Greenberg, 2013; van den Noort et al., 2019). However, variation among findings should be explained rather than dismissed. One recent line of research therefore aims to quantify differences in language experience (e.g., Gullifer & Titone, 2020), given that differences in language experience can lead to differential experimental outcomes. "Language experience" consists of multiple dimensions and especially highlights the notion that the distinction between "bilingual" and "monolingual" is not categorical. Another line of research aims to identify which mechanisms underlying task performance (e.g., attention, inhibition, cognitive flexibility, updating) are modulated by language experience (e.g., Bialystok & Craik, 2022).

The current study is an example of the latter, aiming to identify whether language experience also affects lower-level cognitive mechanisms (in particular feature-integration and feature-unbinding), or mainly top-down mechanisms such as attentional disengagement. To probe into these proposed mechanisms, we used a Partial Repetition Cost task (Hommel et al., 2004), comparing bilinguals and monolinguals. This task does not involve within-trial conflict, as is the case in Flanker or Simon tasks, but probes effects of repetition of features (color, location, response features) on response times. To preview our results, our data suggest that bilinguals more efficiently disengaged attention from task-irrelevant stimulus features, but we observed no group differences in performance on task-relevant stimulus features. This suggests that language experience affects higher-level cognitive mechanisms (attention) more than lower-level mechanisms.

1.1 Overview of past findings

Numerous studies have investigated "bilingual" and "monolingual" performance in cognitive control tasks such as the Simon task (Bialystok, 2006; Bialystok et al., 2005; Kheder & Kaan, 2021; Li et al., 2021) or the Flanker task (Chung-Fat-Yim et al., 2021; Costa et al., 2009; Luk et al., 2010). Some studies have found no group differences in behavioral measures

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such as overall response time (RT) (e.g., Grundy et al., 2017; Lehtonen et al., 2018; Nichols et al., 2020; van den Noort et al., 2019); some studies have found faster responses in monolinguals (e.g., Paap & Sawi, 2014). However, many studies have found faster responses in bilingual groups in specific conditions (e.g., Costa et al., 2009), or have reported reduced conflict effects, either behaviorally or electrophysiologically (Costa et al., 2008; Grundy & Bialystok, 2018).

Shorter overall RTs in cognitive control tasks, or reduced RT differences between conflict and non-conflict trials (conflict effect) have generally been interpreted as more efficient executive function (EF) skills, with past studies attributing shorter RT in conflict interference tasks to more efficient inhibitory skills (Green, 1998). More recent studies attribute shorter RT to monitoring (Hilchey & Klein, 2011), or more efficient attentional disengagement skills (Bialystok & Craik, 2022; Grundy & Bialystok, 2018; Grundy et al., 2017). These latter accounts can also explain the finding that some bilingual participants exhibit shorter RT not only on conflict trials, but also on non-conflict trials, where no inhibition is needed. Bilingualism may impact attentional control – or more specifically, attentional disengagement – because when managing two languages, bilinguals need to disengage attention from the non-target language and reengage attention to the target language, despite language coactivation.

Further evidence for attentional disengagement comes from Grundy and Bialystok (2018). Grundy and Bialystok conducted a task-switching EEG experiment in which trials could be preceded by trials with conflicting information or not. Monolingual participants exhibited larger ERP effects in a late time window following conflict trials than following no conflict trials, whereas bilinguals did not. The groups did not differ in behavioral measures. Grundy and Bialystok took a lack of post-conflict ERP effects in bilinguals to be indicative of more efficient attentional disengagement, since bilinguals were less affected by preceding conflict trials.

2. Congruency Sequence Effects

While many studies have investigated interference costs (or conflict effects) in bilinguals and monolinguals, few have investigated congruency sequence effects (CSEs). CSEs are an index of RT difference between a conflict and a non-conflict trial, but as a function of the type of immediately preceding trial. Typically, responses on a trial will be faster if this trial matches the preceding trial type. For example, RT on an incongruent trial will be shorter if the preceding trial was also incongruent than when the preceding trial was congruent. Similarly, RT on a congruent trial will be shorter if the preceding trial was also congruent than when the preceding trial was incongruent. As a result, the conflict effect (RTs for incongruent minus congruent trials) is smaller if the preceding trial was incongruent rather than congruent. Many different theories of cognitive control have been posited to account for CSEs (for a review, see Egner, 2007). Some theories account for CSEs from a top-down perspective (e.g., conflict monitoring theory –Botvinick et al., 2001; and repetition expectancy – Gratton et al., 1992), whereas others account for CSEs from a bottom-up perspective (e.g., Theory of Event Coding – Hommel et al., 2004); for additional accounts, see e.g., Huffman et al. (2020); Mayr et al. (2003) and Weissman et al. (2014).

A prominent account of top-down cognitive control is Botvinick et al.'s (2001) conflict monitoring theory. The conflict monitoring theory implicates the anterior cingulate cortex (ACC) in conflict adaptation; when conflict is encountered, the ACC is activated, which in turn heightens cognitive control. For example, incongruent trials would induce conflict, thus heightening cognitive control resources, in turn making it easier to process a subsequent incongruent trial (reflected through, e.g., shorter RTs for the second incongruent trial). However, some researchers (e.g., Hommel et al., 2004; Mayr et al., 2003) have posited that the findings in studies such as Gratton et al. (1992) and Botvinick et al. (2001) can be explained by feature-integration and feature-repetition; for example, reduced CSEs on incongruent trials that follow incongruent trials may be due to stimulus repetition in half such trial sequences, and not due to upregulation of cognitive control (see also Weissman et al., 2014); in other words, feature-integration and repetition may indirectly influence CSE results.

Bottom-up accounts explain CSE effects in terms of specific properties of the stimuli presented (Mayr et al., 2003). Bottom-up accounts are typically referred to as "associative" accounts (e.g., Duthoo et al., 2014; Egner, 2014; other approaches include contingency and temporal learning, e.g., Schmidt & Weissman, 2016). A prominent theory of bottom-up cognitive control is the Theory of Event Coding (TEC) (Hommel et al., 2004) in which as stimulus-features repeat, they become bound or integrated into "event files" which are stored in episodic memory. Features that repeat on subsequent trials can reactivate these event files. If the event file reactivated from memory is a complete match with the trial at hand, responses are facilitated, leading to shorter RTs and higher accuracy. If the trial at hand only partially matches the event file reactivated from memory the event-file binding needs to be undone, leading to slower and less accurate responses. The repetition and integration of features can thus account for CSEs, though this is due to stimulus-specific attributes, rather than higher-order cognitive processes such as upregulation of conflict monitoring.

Few studies have directly investigated the effect of language experience on CSE effects. Grundy et al. (2017) investigated CSEs in bilinguals and monolinguals, using both behavioral and electrophysiological methods. Behaviorally, they found smaller CSEs in bilinguals than in monolinguals in a non-verbal Flanker task and a verbal flanker task, in the latter only when the interval between stimulus and response was short (500ms). In a separate EEG experiment, they observed no behavioral group differences in CSEs in a flanker task, but they did observe electrophysiological group differences, with bilinguals exhibiting smaller CSEs as indexed by the N2 and P3 components. Grundy et al. interpreted their results as differential efficiency in attentional disengagement between language groups (but also see Goldsmith & Morton, 2018; and the response by Grundy & Bialystok, 2019). However, it is unclear to what extent reduced CSEs are due to feature-repetition and feature-integration/unbinding, attentional control, or conflict monitoring, none of which can be ruled out in the Grundy et al. (2017) study.

3. The Current Study

Given the potential influence of feature-integration and feature-repetition processes in CSEs observed in traditional cognitive control tasks such as the Flanker Task, the current study investigated bilingual and monolingual performance using the Partial Repetition Cost (PRC) task paradigm (Hommel et al., 2004; Huffman et al., 2020). That is, we sought to investigate whether results between bilinguals and monolinguals would differ related to feature integration and feature repetition processes. If so, this would lend support to the view that the smaller CSE effects observed for bilinguals in prior tasks could be attributed to differences in lower-level processes instead of, or in addition to, higher level cognitive control such as attentional disengagement.

The PRC task specifically probes the effects of feature repetition. Within each trial of the PRC task, participants see three stimuli in the following order: a response cue (RC), a cued response stimulus (CRS) followed by a discrimination response stimulus (DRS, see Figure 1). The RC has arrows either all pointing to the left or all pointing to the right. Participants do not respond to the RC. Participants respond 'left" or "right" to the CRS based on the arrow direction of the preceding RC. At the DRS, participants respond "left" or "right" depending on its color. Thus, participants respond to the CRS based on a property of the preceding stimulus, ignoring properties of the CRS. The DRS is the critical stimulus in the task. Participants need to respond to the DRS solely based on its properties, ignoring the properties of the preceding CRS.

Stimulus color (blue or green), location (top or bottom), and response type (left or right) may repeat or switch between the CRS and the DRS. Color, location, and response features are either fully, partially, or never repeated between the cued response stimulus and discrimination response stimulus. In the full-repetition condition, all features – color, location, and response – repeat between the cued response stimulus and the discrimination response stimulus (see Figure 1, top row). In the no-repetition condition, no features – color, location, or response – repeat between the CRS and DRS (see Figure 1, bottom row). Finally, in the partial repetition condition, only some features (for example, only location, but not color and response) repeat between the CRS and DRS (see Figure 1, center row).

Performance on the PRC task can be explained by the binding and unbinding of stimulus features. The complete repetition or complete switch of features between the CRS and DRS facilitates DRS responses because the memory representation of features does not need to be unbound between the preceding and current stimuli. In contrast, partial repetition trials (e.g., where color repeats but type of response does not) makes it more difficult for participants to respond to the DRS because the association between e.g., the color and the response of the preceding CRS needs to be unbound in order for participants to quickly and accurately respond to the current stimulus. In a no-repetition trial, the features of the preceding CRS are different from those of the current DRS, so no unbinding of prior associations needs to occur. In contrast to, e.g., Flanker tasks, the stimuli in a PRC task do not involve inherent conflict, hence PRC effects cannot be attributed to upregulation of higher-level cognitive control (Botvinick et al., 2001). In line with past literature investigating PRCs, we predicted that the PRC effects would primarily lead to interactions between color repetition and response repetition, and between location and response repetition. We expected that all participants would exhibit longer RTs and lower accuracy on trials where the type of response was repeated but the color (or location) was not, or when the type of response switched but the color (or location) was repeated; shorter RTs were expected for trials in which the type of response and color (or location) either both repeated or both switched. In other words, we expected cross-over interactions between response repetition/switch and color repetition/switch, and between response repetition/switch and location repetition/switch. Studies typically do not find significant triple interactions between color repetition, location repetition and response repetition (Huffman et al., 2020).

If language experience affects bottom-up processes such as binding and unbinding of features, bilinguals in this study would exhibit a smaller partial repetition cost than monolingual participants. That is, we expected the size of the interactions (e.g., response repetition/switch by color repetition/switch, or response repetition/switch by location repetition/switch) to be smaller for the bilinguals than for the monolinguals across-the-board. If, on the other hand, language experience does not affect feature binding and unbinding, the partial repetition costs will be of similar size for the groups. Finally, if bilinguals have more efficient attentional control – defined in line with Grundy et al. (2017) and Grundy and Bialystok (2018) as more efficiently directing attention away from irrelevant stimuli (attentional disengagement) – and are better at directing their attention away from the features of the cued response stimulus, the size of the group differences with respect to the partial repetition costs was expected to be modulated by the task-relevance of the features.

4. Method

4.1 Participants

Participants were recruited via the online platform Prolific (www.prolific.com). We first conducted a screening task with 350 participants. Based on the responses on the screening, participants were invited to take the PRC task.

Prolific allows researchers to set settings such that one can narrow the participant pool based on participants' profile information. We therefore used two different settings in Prolific for our screening study to optimally target early bilinguals and monolinguals. To target monolinguals, we set selection settings such that participants were raised in their native language only and indicated to speak only their native language fluently. Bilinguals were targeted by selecting those who were raised with two or more languages and indicated to speak the native language plus one other language fluently. For both monolinguals and bilinguals, we restricted participants to be between the ages of 18 to 40 years old.

The screening task consisted of the LEAP-Q (Marian et al., 2007), conducted on the platform FindingFive (FindingFive Team, 2019). This included questions about demographic information and language background. In addition, we included questions about learning/reading disabilities, and color blindness, as ability to perceive color differences was essential for PRC task completion.

Based on the self-reported answers on the screening, participants were invited back to take part in the PRC study if they met the following criteria. In order to qualify for the bilingual group in the PRC study, participants had to have acquired both languages before the age of 12. In order to qualify for the monolingual group in our study, participants had no functional proficiency or immersive experience in an L2, or learning experiences beyond two years of high school classroom foreign language study. For both groups, participants indicated they had no learning, reading, or hearing disabilities, and no color blindness.

Sixty-four of the 350 initial participants completed the PRC study. PRC data from 7 participants were excluded from analysis (see 'data analysis'), yielding a total number 24 bilingual (mean age = 28; 9 female, 13 male, 2 non-binary) and 33 monolingual datasets (mean age = 30; 19 female, 13 male, 1 non-binary), for

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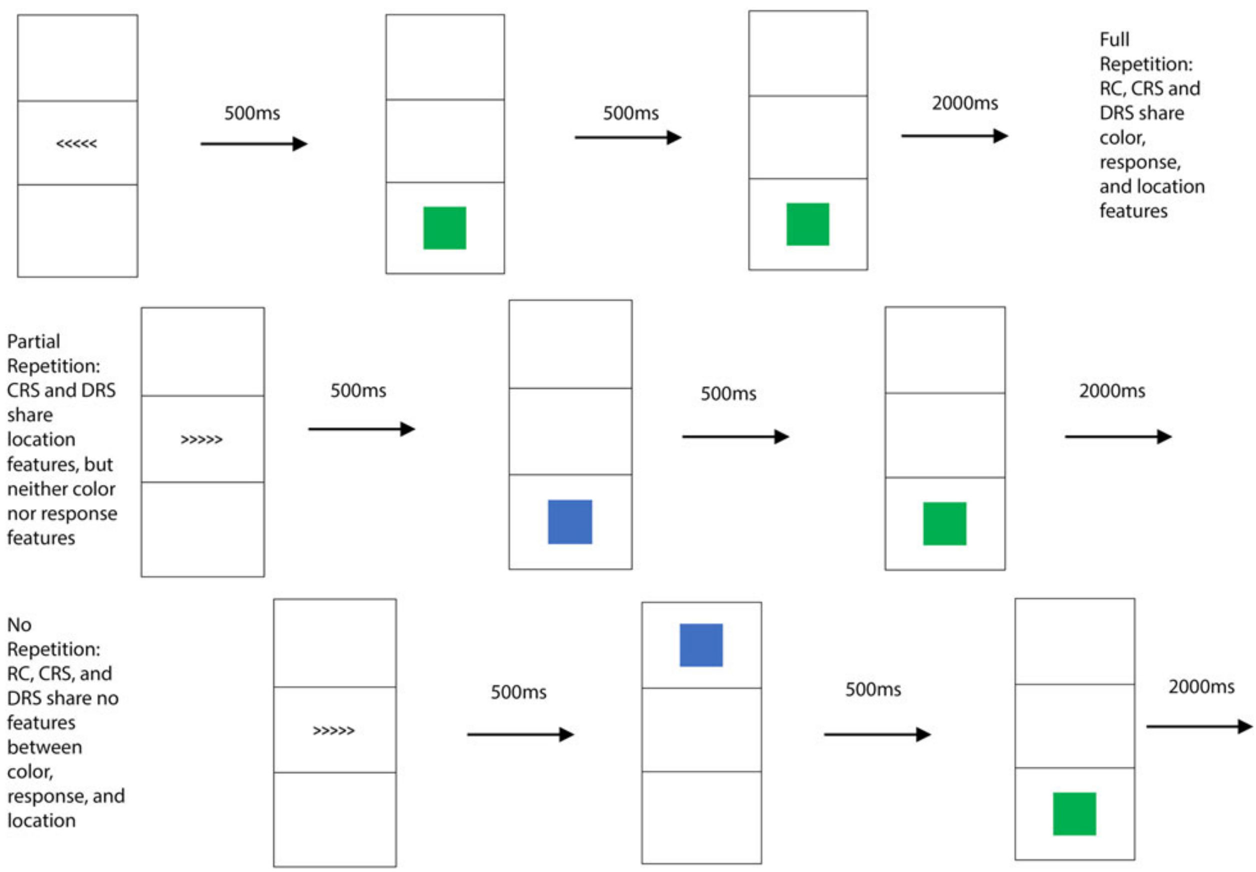

Figure 1. Overview of the PRC trial structure and conditions. Participants do not respond to the RC. Participants respond "left" or "right" to the CRS depending on the direction indicated by the RC. In this example, participants respond "left" on the DRS when the color is green, and "right" when the color is blue. Repetition of features is between the CRS and DRS. Top: Full Repetition. Both the CRS and DRS share spatial, color, and response features. Center: Partial Repetition. Both the CRS and DRS share location features, but have different response and color features; Bottom: No Repetition. There is no overlap between the CRS and DRS in response, color, or spatial features.

a total of 57 datasets. Demographic and other information for the two selected groups can be found in Table S1 in the supplementary materials.

An independent samples t-test revealed that the groups of 24 bilinguals and 33 monolinguals did not differ significantly in age [$T(55) = -1.5$, $p = 0.13$]. Collapsed over listening, written, and spoken proficiency, participants in the group of 24 bilinguals self-rated their proficiency in their first language as 9.0 out of 10 on average (SD 1.6), and in their second language as 8.8 (SD 1.5). They indicated to be currently exposed to their first language 55% of the time (SD 22%), and to their second language 45% (SD 22%). This indicates that the participants in the bilingual group considered themselves fluent in both languages and were currently using both languages. On average, participants in the group of 33 monolinguals self-rated their first-language proficiency as 9.8 (SD 0.5) and indicated their first-language exposure to be 99.7% (SD 1.7%).

4.2 Partial Repetition Cost task

The Partial Repetition Cost task was conducted using the online platform FindingFive (FindingFive Team, 2019). We based our PRC task on Huffman et al. (2020) experiment 2.

The trial structure is illustrated in Figure 1. Participants were first presented the RC for 500 ms, to which they made no response. A 500 ms fixation followed the RC, and then participants were presented with the CRS. Participants were instructed to respond to the CRS based on the arrow direction of the RC; they were instructed to press 'F' on the CRS if the RC arrows faced left, and they were instructed to press 'J' on the CRS if the RC arrows faced right, regardless of the nature of the CRS. The CRS remained on the screen until participants made a response. The response was followed by a 500 ms fixation, after which participants saw the DRS. Participants were instructed to respond to the DRS based on its color. Half of the participants were instructed to press 'F' if the DRS was green, and 'J' if it was blue; the other half was instructed to press 'J' if it was green, and 'F' if it was blue. The DRS remained on the screen until participants made a response. The interval between trials was 1000 ms.

There was a total of 32 possible feature combinations, randomly repeated 7 times across the experiment, yielding a total number of 224 experimental trials. Participants were first presented with 32 practice trials before seeing the 224 experimental trials.

4.3 Analysis

We excluded 7 data sets of the 64 collected in the PRC task. These were participants who scored less than 80% correct on the CRS or

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DRS trials and could therefore be assumed to not have paid attention or understood the instructions. The remaining 57 data sets (24 bilingual, 33 monolingual) were preprocessed as follows. First, trials to which the CRS was responded incorrectly were excluded, as well as trials in which CRS or DRS response times (RTs) were shorter than 100 ms. This is too short to be a response to the current stimulus. This affected 6.2% of the data (751 data points). In addition, we omitted trials in which the CRS or DRS RT was longer than 3000 ms. This latter procedure removed another 1.6% (199) of the data points. The number of trials affected by this cutoff were equally distributed across the groups and conditions, with 1-3% affected per cell. Accuracy analysis was conducted on the resulting dataset (11244 data points). RT analysis was conducted on trials on which the DRS was responded to correctly (omitting another 185 data points, yielding a data set of 11059 data points).

Data analysis was conducted in R version 4.1.2 (R Development Core Team, 2021) using brms (Bürkner, 2017), which is a wrapper around stan (Stan Development Team, 2021).

Accuracy data for the DRS were analyzed using a Bayesian mixed effects model using a bernouilli distribution with a logit link function. Accurate responses were coded as 1 and inaccurate as 0. The fixed effects were Response repetition, Color repetition and Location repetition, with no-repetition coded as −1 and repetition coded as 1. Group was included as an additional fixed effect with bilingual coded as −1 and monolingual as 1. In addition, the model included all interactions between these factors. Random effects were by-participant intercepts, and Response, Color, and Location repetition and their interactions as by-participant random slopes. We used mildly-informative priors. The prior for the intercept for the accuracy analysis was a normal distribution with a mean of 0 and an SD of 10. This means we could be 95% sure that the estimated mean accuracy would fall between −10 and 10 on the log-odds scale (0 to 100% on the probability scale). The priors for the coefficients corresponding to the fixed effects and their interactions were set to a normal distribution with a mean of 0 and an SD of 1. That is, if the mean accuracy is 2 (.88 on probability scale), we could be 68% sure that the effect is smaller than −1.27 in logits, which is 0.22 on the probability scale. The prior for the standard deviations was a normal distribution truncated at 0 with a mean of 0 and an SD of 1. Finally, LKJ priors with a ν of 2 (Lewandowski et al., 2009) were used for correlation matrix of the random effects.

DRS RT data was analyzed using a Bayesian linear mixed effects model using a lognormal family. This was because our data were right skewed, as is typical for response time data. Fixed and random effects were the same as in the accuracy analysis. Priors for the intercept were a normal distribution with a mean of 6 and an SD of 1.5. This means that we expected the mean RT to fall between 90 and 1808 ms with 68% certainty, and between 20 and 8103 ms with 95% certainty. The remaining priors were set the same as in the accuracy analysis. This means that if the intercept is 6 on the log scale (403 ms), the absolute size of the effects of interest will be smaller than 6.85 (948 ms) with 68% certainty.[1]

Models were estimated using four sampling chains run with 4000 iterations each, of which the first 1000 were warm-up. Adapt_delta was set to 0.99. In all analyses, Rhat was 1 or 1.01 indicating no problems in model convergence, and the bulk effective sample size was greater than 400 (Vehtari et al., 2021). We report the mean and 95% credible intervals (CrI) of the posterior distributions of the effects of interest, back-transformed to probability space or milliseconds. Data and scripts are available on the Open Science Framework: https://osf.io/sxz2q/.

5. Results

5.1 Accuracy data

Figure 2 depicts the mean accuracy for response repetition and color repetition (Figure 2 panel a); and response and location repetition (panel b). We obtained the partial repetition cost effect: accuracy was higher when response type and color (or location) either both repeated or both switched between the CRS and DRS, compared to when only one feature repeated. This pattern could be seen in both bilinguals and monolinguals.

Posterior distributions and 95% credible intervals of the fixed effects are given in table S2 in the supplementary materials; results for effects of interest are depicted in Figure 3. The estimate of the Response repetition by Color repetition effect was, in probability space 0.95% CrI:[0.51, 1.47], and the interaction of Response repetition by Location repetition was 0.42% CrI:[0.11,0.77]. Estimated effects involving Group were small, ranging from 0.02% CrI: [−0.32, 0.36] to −0.14% CrI:[−0.45, 0.14] for interactions, and 0.24% CrI:[−0.62, 0.09] for the main effect of Group, with all credible intervals including zero.

5.2 RT data

Mean RTs are given in Figure 4. Results of the Bayesian analysis for the response times are given in Table S2 in the supplementary materials. Figure 5 depicts the posterior distributions and 95% credible intervals of the fixed effects of interest. Following the pattern in the accuracy data, we observed partial repetition cost effects in the response time data, with RTs being shorter when response and color either both repeated or both switched, as compared to when only one feature was repeated between the CRS and DRS. The posterior estimates of the Response repetition by Color repetition effect (−50ms CrI:[−61; −40]), and of the Response repetition by Location repetition effect (−16ms CrI:[−24;−8]), were both rather large and had credible intervals that did not contain 0.

The bilingual and monolingual groups showed similar partial repetition cost effects for the color and response features (Group by Response repetition by Color repetition: 1 ms, CrI: [−10, 11]), see Figure 5). However, the bilinguals showed smaller partial repetition costs for the location and response features (Group by Response repetition by Location repetition (−8 ms, CrI:[−17, 0]). There was also a substantial difference on overall RTs between the groups, with bilinguals responding more slowly than monolinguals, but this effect had a large uncertainty (−87 ms CrI:[−180,4]).

To further investigate the triple interaction between group, response repetition and location repetition, we re-ran the model, once with the level of bilingual coded as the reference level, and once with the level of monolingual as the reference level (see Tables S4 and S5 in supplementary materials). The estimated interaction effect of response repetition by location repetition was much smaller in absolute size when the reference level was the bilingual group (−8 ms CrI:[−22, 5] with only 11% of the distribution larger than 0) than when the reference level was the monolingual group (−23 ms CrI:[−34, −13]; distribution not containing 0). The estimated partial repetition cost was

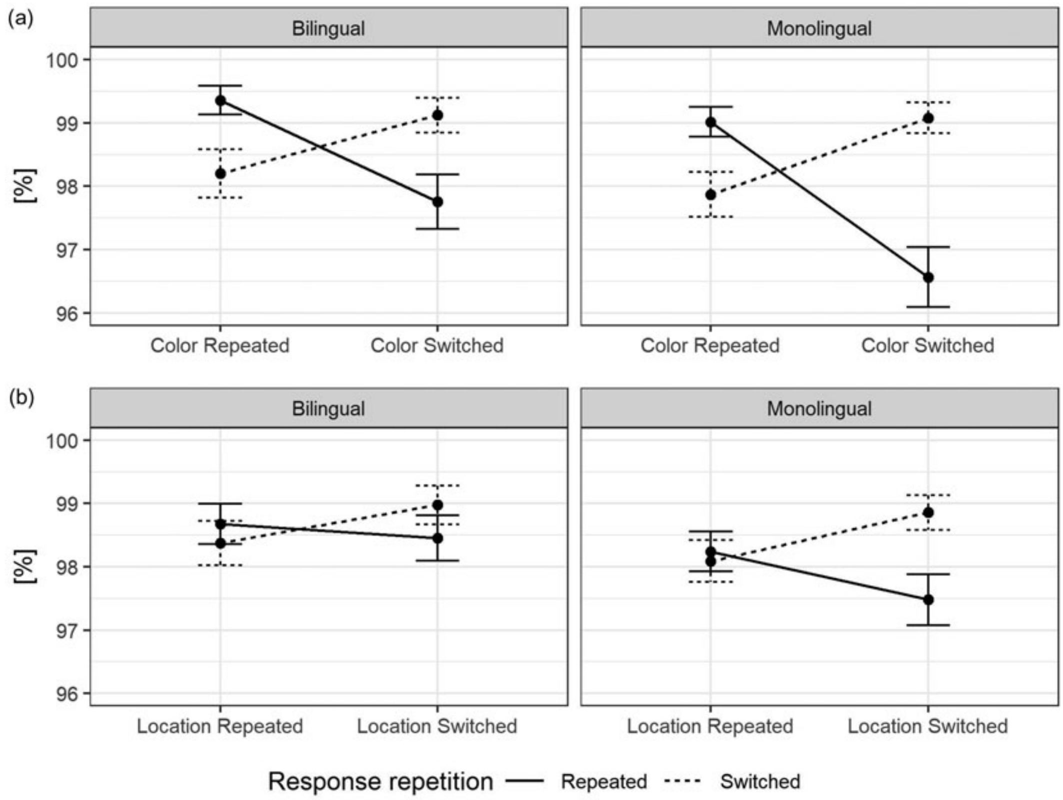

Figure 2. Mean accuracy (in percentage) for the DRS. (a) Response by color repetition; (b) Response by location repetition. Left column, bilinguals; Right column, monolinguals. Error bars are standard errors.

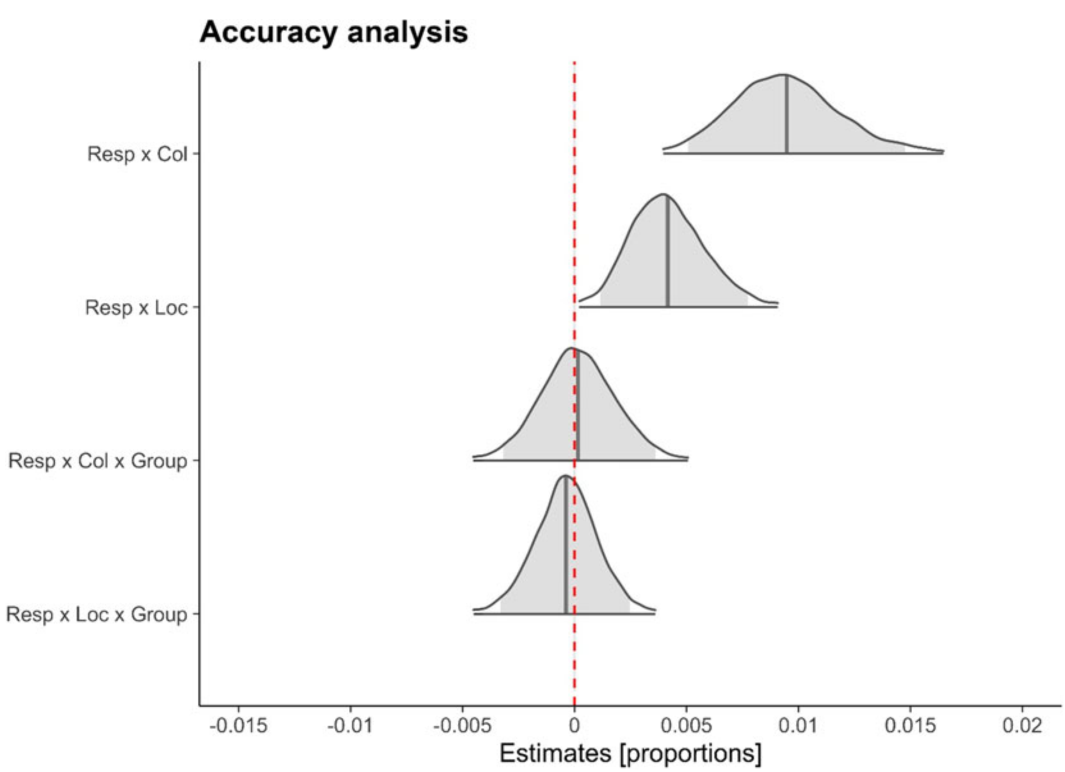

Figure 3. Posterior probability distributions of effect sizes of interest for the accuracy data. In this and other figures, the red dotted vertical line corresponds to an effect size of 0; solid vertical line indicates the posterior mean; shaded areas indicate the 95% credible intervals. "Resp": response repetition; "Col": color repetition; "Loc": Location repetition.

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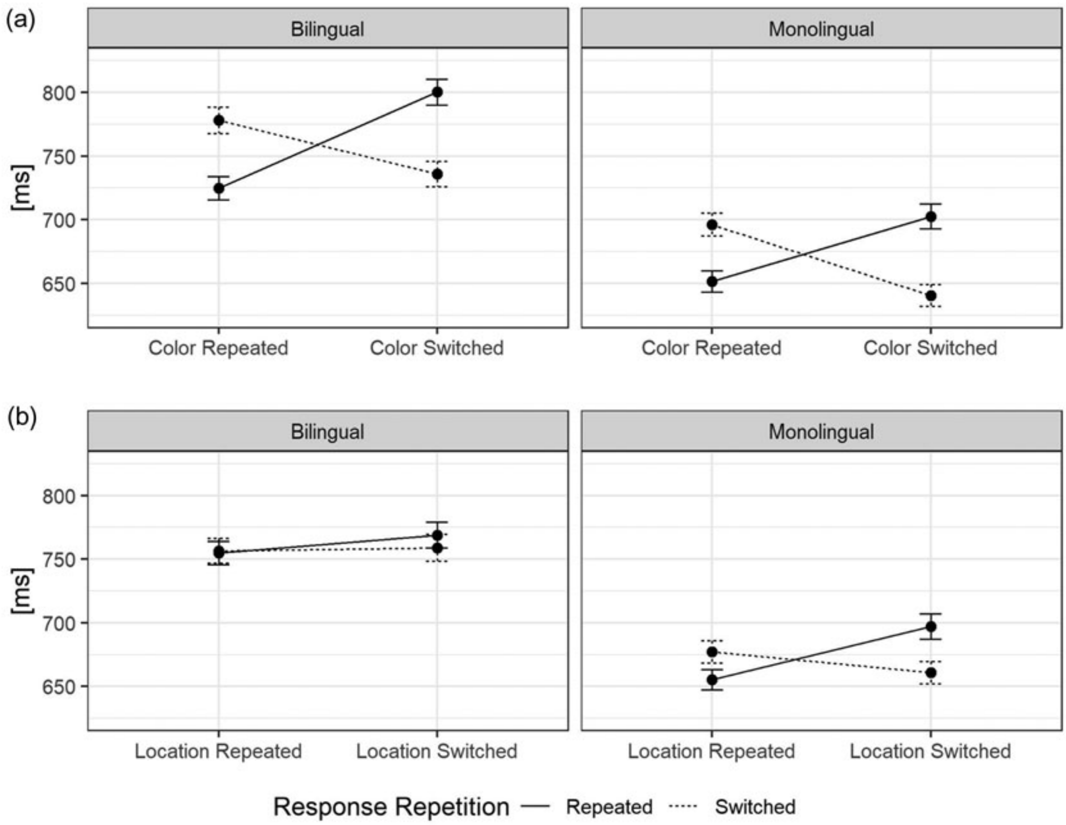

Figure 4. Mean Response times (ms) for the DRS. (a) Response by color repetition; (b) Response by location repetition. Left column, bilinguals; Right column, monolinguals. Error bars are standard errors.

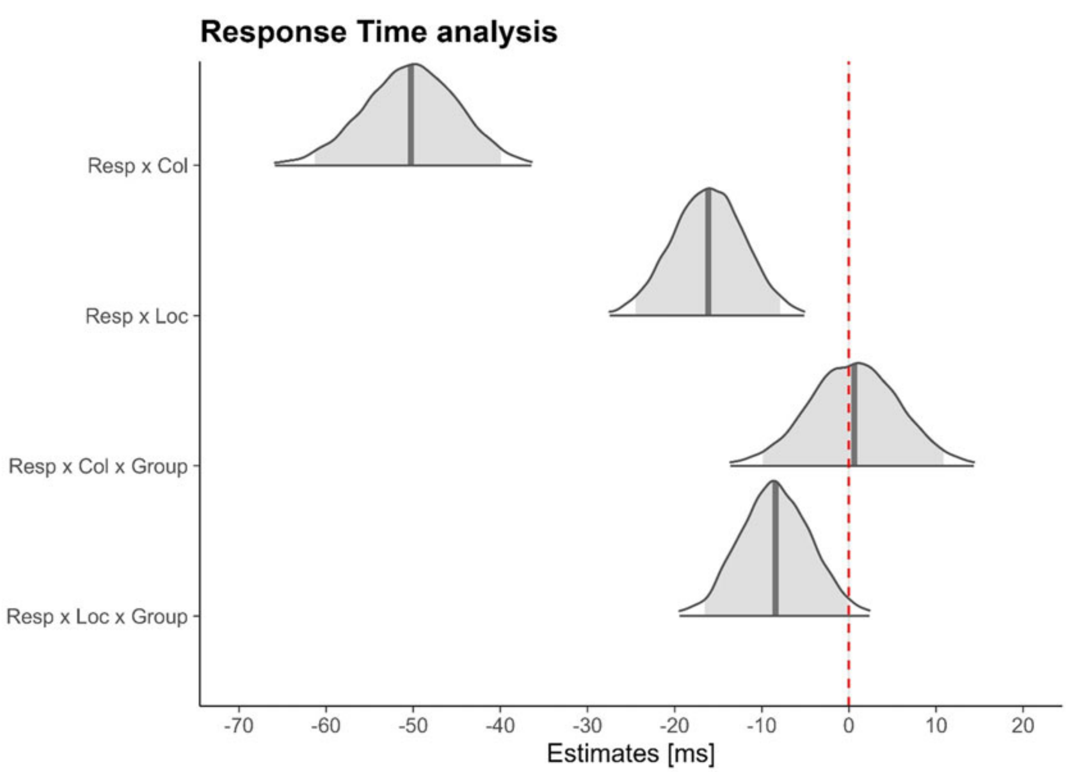

Figure 5 Posterior probability distributions of effect sizes of interest for the RT data. "Resp": response repetition; "Col": color repetition; "Loc": Location repetition.

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therefore smaller in the bilingual group than in the monolingual group when the features involved response and location.

5.3 Bayes Factor Analysis

The above analysis suggests that the difference in partial repetition cost between the bilinguals and monolinguals is around 8 ms in size for the response and location feature combination, and around 1 ms for the response and color feature combination. However, this does not say anything about the extent to which the data support a model with the triple interaction over a model without. We therefore conducted a Bayes Factor Analysis comparing the original RT model with a model without the critical triple interaction as fixed effect (the null model). We separately assessed the Group x Response repetition x Color repetition effect, and the Group x Response repetition x Location repetition effect. Outcomes of Bayes Factor analyses are very sensitive to priors. We therefore used three different priors for the effect of interest. All were normal distributions with a mean of 0. We varied the standard deviation of the priors for the interaction in three ways: (1) sd = 1, as in the original model; (2) sd = 0.1 which means that assuming a mean RT of 6 (450 ms), the effect is with 68% certainty expected to be smaller than 81 ms; and (3) sd = 0.01, which means that the effect is expected to be smaller than 8 ms with 68% certainty. Each model was run with 4 chains of 20,000 iterations of which 2500 were warmup. The marginal likelihood was compared for each model versus the null model without the triple interaction, yielding the Bayes Factor. Conventionally, Bayes Factor values larger than 3 can be taken as evidence for the alternative model over the null model, with values over 10 taken as strong evidence; factors smaller than 0.3 are taken as support for the null model over the alternative model, with values lower than 0.1 as strong evidence for the null model. (Jeffreys, 1961; Lee & Wagenmakers, 2013). Results for the Group x Response repetition x Color repetition interaction are given in Table 1. Using a (0,1) or (0, 0.1) prior resulted in strong evidence in favor of the null model – that is, the data supported a model without group differences regarding the Response x Color partial repetition effect.

Results for the Group x Response repetition x Location repetition interaction are given in Table 2. The outcomes support the null model with the (0, 1) prior, but yield anecdotal evidence for the model with the interaction with priors assuming very small effects. The Bayes Factor results are therefore inconclusive for this effect: we do not have any meaningful evidence supporting the model with the triple interaction between Group, Response and Location repetition over the one without, or vice versa.

Table 1. Comparing the effect of different priors on the Bayes Factor. The models being compared are linear mixed effects models with (1) and without (0) the Group x Response repetition x Color repetition factor. BF_{10} is how much the first model is supported over the null model.

Priors	BF_{10}	Posteriors (ms)		
(log space)		Estimate	Lower 95% CI	Upper 95%CI
Normal(0, 1)	0.00	1	−10	11
Normal(0, 0.1)	0.04	1	−10	11
Normal(0, 0.01)	0.34	1	−9	10

Table 2. Comparing the effect of different priors on the Bayes Factor. The models being compared are linear mixed effects models with (1) and without (0) the Group x Response repetition x Location repetition factor. BF_{10} is how much the first model is supported over the null model.

Priors	BF_{10}	Posteriors (ms)		
(log space)		Estimate	Lower 95% CI	Upper 95%CI
Normal(0, 1)	0.02	−8	−17	0
Normal(0, 0.1)	0.27	−8	−17	0
Normal(0, 0.01)	2.17	−8	−16	0

5.4 Summary of results

We found classic PRC effects: accuracy was higher and responses faster when response and color features either both were repeated or both switched compared to when either response or color was repeated. The same pattern was found for response and location repetition, even though the size of the interaction was smaller. Our main question concerned in what respect and to what extent bilinguals and monolinguals differed on the PRC task. The groups did not differ in the PRC patterns observed for accuracy. Bilinguals had overall longer response times but showed similar partial repetition costs for Response by Color repetition as the monolinguals. Results of the Bayes Factor analysis strongly supported a model with no group differences as to the Response by Color repetition effects.

However, bilinguals showed a smaller interaction of Response by Location repetition, suggesting they were less affected by the location-response features of the prior stimulus (the CRS). Bayes Factor analysis however did not provide enough evidence for either a model with or a model without the triple interaction of Group by Response repetition by Location repetition. We therefore need to be careful in interpreting this triple interaction effect in the response times based on the current data.

6. Discussion

The current study investigated whether bilinguals and monolinguals differ in bottom-up processes, or in top-down cognitive control (such as attentional disengagement) as has been traditionally posited. Paradigms that have been used previously to assess cognitive control and attentional disengagement in bilinguals, such as CSE paradigms, may have been influenced by bottom-up processes related to stimulus properties. We therefore tested whether bilinguals and monolinguals differ in their performance in a partial repetition cost paradigm. We predicted that if past results reflected bilinguals being better at bottom-up processes, then bilinguals would exhibit smaller partial repetition cost effects across the board. However, if bilinguals have more efficient attentional control and are better at directing their attention away from the features of the cued response stimulus, the size of the group differences with respect to the partial repetition costs was expected to be different depending on whether features were task relevant (color in our case) or task-irrelevant (location in our case).

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Our results support the latter view. First, we observed a large partial repetition cost effect for color and response features. RTs were shorter when response and color features repeated between the CRS and the DRS. This can be attributed to the binding and unbinding of features: repetition of features across CRS and DRS trials fully reactivates the event file formed in the CRS, leading to shorter response time on the DRS. In trials in which the CRS and DRS only matched in response but not in color, or matched in color but not in response, the response-color association of the CRS had to be unbound, leading to longer RTs. Similar PRC effects were observed for accuracy: accuracy was lowest when either the response or the color feature switched. The bilinguals and monolingual groups did not differ in the size of the partial repetition cost effect for color and response features. Thus, our results suggest that both groups recruit bottom-up processes (feature binding and unbinding) in a similar way. This finding also suggests that results from prior studies showing group differences between bilingual and monolingual participants are likely not due to differences in bottom-up processes.

Importantly for our research question, we did observe differences between the language groups in the PRC involving the location feature. Here monolinguals showed large PRC effects (23 ms); the bilinguals showed a much smaller effect (8 ms). We need to be careful in interpreting this group difference, since results from the Bayes Factor analysis for the Group x Response repetition x Location repetition were inconclusive.

We discuss two accounts for the data patterns observed. The first interpretation aligns with Grundy et al.'s (2017) explanation of smaller CSEs owing to more efficient attentional disengagement. Under this interpretation, bilinguals more efficiently disengaged attention from the irrelevant stimulus feature location. Bilinguals exhibited smaller partial repetition costs than monolinguals for location features. However, PRCs did not differ between bilinguals and monolinguals for response repetition by color repetition. Color was the most salient feature, one to which participants were explicitly instructed to respond. In contrast to color, participants were not instructed to respond to location; that is, the location feature was irrelevant to the task. In the latter case, bilinguals were more efficient at modulating attention away from the irrelevant features of the cued response stimulus. In their daily lives, bilinguals need to often disengage attention from one language to focus on another. This ability may carry over to non-linguistic tasks.

A second potential interpretation is related to the bilinguals responding much more slowly overall than monolinguals. Slower response times allow for inhibition or attentional disengagement to become stronger, suppressing the task-irrelevant location information more, and/or allowing more time to divert attention (Grundy et al., 2017). This second account implies that the reduction of the PRC effect for location is not specific to the bilingual experience but is related to overall response times. This predicts that also monolinguals will show a reduction of the Response by Location repetition interaction when their response times are longer. To explore this issue, we divided the participants into 4 groups (quartiles) based on their average RT on the DRS and plotted the Response by Location repetition interaction effect for each quartile and language group (see supplementary Figure S1). As participants' response times became slower, the interaction effect became larger (in absolute terms) for the monolinguals. This is the opposite of what one would expect if slower response times allow for inhibition or attentional disengagement to become stronger. This suggests that the smaller interaction effect we obtained for the bilinguals cannot be fully attributed to bilinguals responding more slowly overall. Rather, the smaller interaction effect is likely to be associated with the bilingual experience.

Our findings are reminiscent of results reported by Morales et al. (2013). Morales et al. investigated cognitive control differences between bilinguals and monolinguals using an AX-CPT task. Bilinguals in their study showed a similar behavioral pattern to the bilinguals in our study, in that they had slower overall response time in comparison to monolinguals. In addition, bilinguals were better in the AY condition, in which an X stimulus is strongly expected but instead a Y stimulus occurs and the prepotent response needs to be inhibited. However, monolinguals and bilinguals did not differ in inhibition on an easier stop-signal task. Morales et al. (2013) interpreted their findings to support the view that bilinguals are better at dynamically adjusting their (pro-, reactive) cognitive control to the contextual demands. Along these lines, our results can be interpreted in terms of attentional modulation. Bilinguals more than monolinguals adjust their attention to the properties of the task – more than monolinguals, bilinguals disengage attention when features are not relevant for the task (such as location in the present task).

Limitations and conclusion

Our study provides support for the view that language experience affects attentional control. However, this study has several limitations. First, due to the study being conducted over the internet, we had a lot of attrition between the screening task and the actual study, leading to a relatively small number of participants per group. Second, this study treated monolingual and bilingual as a categorical distinction for practical purposes. However, we acknowledge that such a distinction is artificial and that individuals differ widely in their language experiences. Recently, many researchers have called attention to the diverse factors that make up the linguistic experience (including e.g., passive language exposure, language use in various contexts), and have put to the forefront that there is no obvious demarcation between bilinguals and monolinguals (e.g., Kaushanskaya & Prior, 2015; Luk & Bialystok, 2013). In spite of this we consider the results from our study valuable since we aimed to compare individuals from groups that occupy different positions on the language experience continuum: those who grew up speaking one language and who are still mainly using that language versus those who grew up speaking two languages and are still using those languages. However, we acknowledge that our results may not generalize to bilinguals with other language experiences.

Finally, the absence of behavioral differences between groups (in particular regarding the Color by Response repetition effect) does not exclude differences at the neural level. For example, whereas Grundy et al. (2017) found no group differences in their behavioral results, they did find group differences in their ERP results. An EEG version of the current study could provide more insight into how and whether language experience affects partial repetition costs.

In conclusion, the results of our study are consistent with the results of past studies, such as Grundy and Bialystok (2018) and Grundy et al. (2017), insofar as they support a view of more efficient attentional disengagement in bilingual participants. Furthermore, our results suggests that bilinguals and monolinguals do not differ in lower-level processes such as feature-integration and feature-repetition given that size of the PRC effect was the same for the two groups for task-relevant features.

Supplementary Material. For supplementary material accompanying this paper, visit https://doi.org/10.1017/S1366728923000731

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Note

[1] Similar results were obtained when a less informative prior for the intercept was used (0, 10).

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