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Brief Report

Masked identity priming reflects an encoding advantage in developing readers

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ABSTRACT

The masked priming technique is widely used to explore the early moments of letter and word identification. Although this technique is increasingly used in experiments with young readers, the mechanism in play during masked priming with early readers has not yet been fully explored. We investigated the masked priming effects from a modeling perspective; we instantiated competing theories as data models (using Bayes factors) and as a computational model (diffusion model). We carried out a masked priming experiment using identity primes with second- and fourth-grade participants, and we analyzed the data through an evidence accumulation model lens. The priming effect manifests as a shift in the response time distribution, which in evidence accumulation models is accounted for by changes in the encoding process. We describe such changes as savings that have three features of theoretical importance. First, they are numerically very close to the stimulus onset asynchrony between primes and targets. Second, they remain relatively constant from second grade to fourth grade. Third, they seem to operate at the level of abstract orthographic representation because the priming effect occurs in both case-matched and case-mismatched pairs. These findings also have consequences for the practice of data transformation in developmental research; some patterns of data, when transformed, would produce spurious effects.

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Introduction

Since its inception, Forster and Davis's (1984) masked priming technique quickly became the most popular paradigm aimed at unveiling the early moments of letter and word identification (see Grainger, 2008, for a review). In this technique, a forward mask is replaced on the screen by a briefly presented prime stimulus (≈30–50 ms), which in turn is replaced by the target stimulus until the participant makes a response (typically a lexical decision). This paradigm allows researchers to manipulate the prime–target relationship (e.g., identity, orthography, phonology, semantics) in the absence of conscious identification of the prime.

The masked priming technique was initially employed with adult readers (Forster & Davis, 1984), but it has also become a gold standard for comparing orthographic processing in young readers of different grades (e.g., Acha & Perea, 2008; Castles, Davis, Cavalot, & Forster, 2007; Kezilas, McKague, Kohnen, Badcock, & Castles, 2017; Lété & Fayol, 2013; Soares, Perea, & Comesaña, 2014; Ziegler, Bertrand, Lété, & Grainger, 2014). While using masked priming with developing readers, an interpretability concern is that the longer response times (RTs) for younger children than for older children make it challenging to compare the magnitude of masked priming effects across age groups. To address this concern, previous masked priming experiments that compared across groups have typically used transformed data (e.g., *z* scores: Ziegler et al., 2014; log-transformed or inverse-transformed data: Acha & Perea, 2008). However, any RT transformation makes assumptions about the nature of the task and how masked priming is modulated by age (we revisit the consequences of transformations in the Discussion).

In the current study, we modeled masked identity priming in lexical decision with developing readers. We chose masked identity priming over other forms of prime–target relationships because it produces the most robust effects and also because there are theoretical accounts in the form of quantitative models that explain the nature of the effect. In this study, the prime and the target were either the same (prime: *arte;* target: *ARTE*) or unrelated (prime: *kiwi;* target: *ARTE*). The mainstream interpretation of masked identity priming is that the prime activates the letter representations at an abstract level, and this provides an encoding advantage for the identity primes over unrelated primes (i.e., "savings" account; see Forster, 1998). That is, an identity prime presented for 50 ms would give a head start to the processing of the target word of about 50 ms compared with an unrelated prime. The savings account makes a straightforward prediction: The RT distributions of the identity and the unrelated condition in masked priming should differ merely in a shift in their location (i.e., there should be a similar effect of priming across all quantiles). One could argue that the difference in the RT of unrelated versus related items could be due to a benefit provided by the identity prime or to the cost induced by the unrelated prime. This issue was addressed by Jacobs, Grainger, and Ferrand (1995), who demonstrated, using a within-participant baseline, that masked identity priming is essentially due to the facilitation from the related prime and not to the inhibition of an unrelated prime.

In a study focused on modeling masked priming with adult readers, Gomez, Perea, and Ratcliff (2013) found that masked identity priming produced a shift in the RT distributions (see left panel of Fig. 2 in Gomez et al., 2013). To account for their data, they set up two competing implementations of the drift diffusion model for the lexical decision task (Ratcliff, Gomez, & McKoon, 2004). In one of the implementations, the priming effect was assumed to affect the encoding processes (the T_{er} [encoding time] parameter of the model); in the other, it was assumed to affect the rate of evidence accumulation (the drift rate parameter of the model). The distributions' shift was best accounted for by the model that assumed that masked priming affects the encoding processes, which supports Forster's (1998) saving hypothesis.

In the Gomez et al. (2013) study, the size of the shift in the RT distributions was virtually identical to the stimulus onset asynchrony (SOA); thus, the main question we addressed in the current study is whether masked identity priming in developing readers can also be modeled as a savings process in an evidence accumulation model (i.e., a shift in the RT distributions similar in size to the SOA) or whether it produces a different pattern—either quantitative (i.e., a shift in the RT distributions larger or smaller than the SOA) or qualitative (i.e., a change in shape in the RT distributions). Although we used Ratcliff's drift diffusion model as our tool, similar distinctions between encoding and decision processes exist in other models (see Brown & Heathcote, 2008); in Fig. 1, we explain how the distinction between encoding and decision processes in the model can generate different predictions in the distribution of RTs.

The second goal of the current experiment was to examine the effect of matching the case (lowercase–UPPERCASE vs. UPPERCASE–UPPERCASE) of primes and targets. Jackson and Coltheart (2001) postulated that developing readers can access abstract orthographic representations once they can name letters in both uppercase and lowercase forms. This suggests that, even in second grade, masked identity priming occurs to the same degree for pairs like *house–HOUSE* and *HOUSE–HOUSE* (see Jacobs et al., 1995, for evidence with adult readers). Perea, Jiménez, and Gomez (2015) replicated the findings of Jacobs et al. (1995) with adults and fifth-grade students; however, their findings with third-grade students were inconclusive. Here, we reexplored this issue with second- and fourth-grade students using a larger number of observations per condition and a model-based approach (see Soares et al., 2014, for a similar choice of grades).

To summarize, in the current work we explored whether there are invariances in masked priming (e.g., whether case matching does not affect the priming effect or whether the effect of priming is the same at these two grade levels). Given this agenda, we chose Bayes factors as our tool for statistical inference. Bayes factors are a way to quantify the evidence in favor of one model over another model in principled ways.

Method

Participants

The participants were 40 second graders (mean age = 7 years 4 months, range = 6.8–7.8 years) and 22 fourth graders (mean age = 9 years 3 months, range = 8.1–9.9 years) from a public school in Spain. Parental consent was collected for all the participants before the experiment. The sample size was larger for second graders because their latency data are substantially noisier than for fourth graders. All participants were native speakers of Spanish with normal scores on standardized reading/cognitive tests and with normal or corrected-to-normal vision.

Materials

We selected 40 Spanish words of four letters from the Spanish EsPal subtitle database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013) with a mean frequency of 59.9 per million words (range = 0.5–325.1). All these words appeared in the LEXIN database (Corral, Ferrero, & Goikoetxea, 2009) for first-grade textbooks. The average number of orthographic neighbors was 6.55 (range = 0–23). We also created 40 orthographically legal pseudowords of four letters to act as foils (e.g., TISE, NAIS, VUCA). The list of word and pseudoword targets is presented in the Appendix. Targets were presented in uppercase and were preceded by either (a) a matched-case identity prime (e.g., ARTE–ARTE), (b) a lowercase identity prime (e.g., arte–ARTE), (c) an unrelated word/pseudoword in uppercase, or (d) an unrelated word/pseudoword in lowercase. Each target stimulus was presented in each condition four times (i.e., 160 word trials and 160 nonword trials), resulting in 40 identity trials and 40 unrelated trials per condition.[1]

Procedure

The experiment took place in groups of 3 or 4 participants in a quiet room. DMDX software (Forster & Forster, 2003) was employed to present the stimuli and register the responses. Stimuli were pre-

[1] Previous research has revealed that the nature of masked identity priming in lexical decision is similar when the items are presented once or when they are repeated several times (see Perea, Jiménez, & Gómez, 2014).

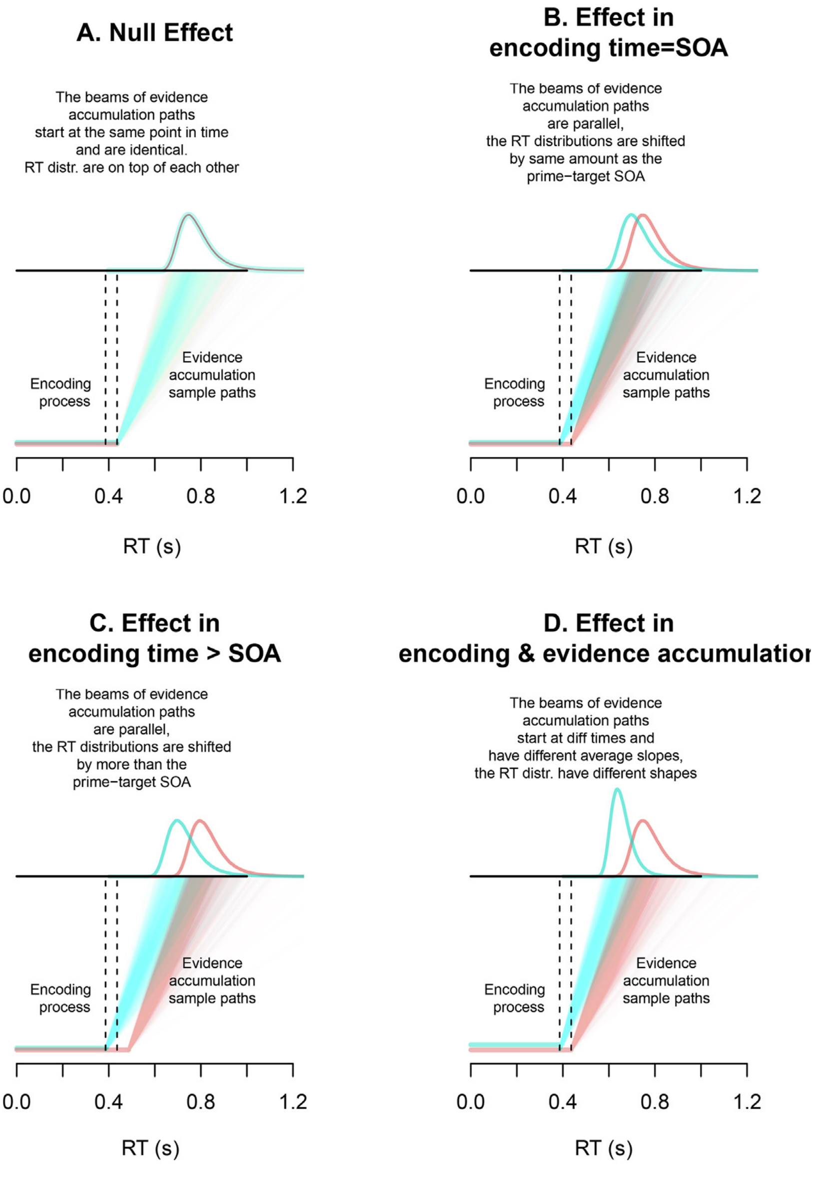

Fig. 1. Graphic representations of the four hypotheses being examined. In all panels, we represent the encoding process as a flat line; during this time, the retinotopic sensory signal is encoded into orthographic representation, but the decision about lexical status has not started. The beams of color represent different average paths of evidence accumulation in one trial (in this case it is evidence in favor of a "word" decision). Note that these are beams to represent the variability across trials in this evidence accumulation. When evidence reaches a decision boundary (the top horizontal line), a response is initiated. Each panel shows the response time (RT) distributions for the hypothesis being illustrated. In Panel A, we represent a null hypothesis in which there is no priming effect. In Panel B, we represent the hypothesis that priming in developing readers is identical to the stimulus onset asynchrony (SOA) between the prime and target (~50 ms savings in the encoding process; the 50 ms is represented by the dashed vertical lines). In Panel C, we represent the hypothesis that priming is of a different size than the duration of the SOA (in the case of the illustration, the effect is larger; note, however, that this hypothesis is agnostic about the direction of the difference). In Panel D, we represent the hypothesis that priming in developmental readers affects both the encoding and evidence accumulation processes. (For interpretation of the reference to color in this figure legend, the reader is referred to the Web version of this article.)

sented in the center of the screen using Courier New font. The structure of each trial was as follows. First, a pattern mask (####) was presented for 500 ms. Second, a prime item was presented for 33.3 ms. Third, a post-mask (####) was presented for 16.6 ms. Finally, a target item was presented until the participant responded or 3 s had passed. Thus, the prime–target SOA was 50 ms; the post-mask was presented to avoid perceptual continuity of primes and targets in the matched-case identity condition. Participants were instructed to press the "yes" key if the uppercase letter string was a Spanish word and to refrain from responding if the letter string was not a word, and both speed and accuracy were stressed in the instructions. The 320 stimuli were divided into two lists in a Latin square design so that every participant took part in two sessions on 2 different days (160 trials each day). In each session, 14 practice trials preceded the experimental phase. There was a short break around the middle of each experiment session. Each session lasted about 12 min.

Results

Error responses (7.6% of all responses for second graders and 4% of all responses for fourth graders) and RTs shorter than 300 ms (<0.2% of all responses for children in both grades) were excluded from the RT analyses. (Note that RTs could not be longer than the 3000-ms trial deadline.)

We present the results from this study in four different sections. First, we examine whether there is an effect of case matching between primes and targets. Second, we analyze the average latency data and the accuracy data. The third section explores the distributional features of the latency effects using delta plots. The final section presents a diffusion model account of the developmental trajectory of masked identity priming.

Effect of case matching

The RTs and accuracies for case-matched versus mismatched identity prime–target pairs all are numerically similar. The mean RTs for related pairs are as follows: match = 1090 ms versus mismatch = 1097 ms (for second graders) and match = 911 ms versus mismatch = 906 ms (for fourth graders). The accuracies are similar as well: match = .910 versus mismatch = .919 (for second graders) and match = .976 versus mismatch = .972 (for fourth graders). Here, we examine whether there is, in fact, evidence supporting a lack of case-match effect ($Model_0$: there is a null effect for case match; $Model_1$: there is a nonzero effect of case match; for both models, we assume an effect of fixed effects of grade and prime–target relation and random effects of participants and items). Indeed, for RT there is a $BF_{0,1}$ = 33, and for accuracy there is a $BF_{0,1}$ = 17; for these inferential analyses, we used the R package *BayesFactor* (Morey & Rouder, 2018) with default priors. Given these results, we decided to simply collapse the two conditions (case match and case mismatch) in the subsequent analyses.

Latency data

Having established that case match between prime and target seems to play no role in the obtained priming effects, we now examine whether the data are consistent with one of the following models:

$Model_{Grade}$: A model in which there is an effect of grade only, not of prime
$Model_{Full}$: A model in which there are main effects and interaction of prime and grade
$Model_{Main}$: A model in which there are only main effects of prime and grade
$Model_{Prime=50ms}$: A model in which we assumed a main effect of grade and also that the effect of identity priming in our groups (second graders vs. fourth graders) is the same as the prime–TARGET SOA.

In all models, prime (identity vs. unrelated) and grade (second vs. fourth) were fixed effects, and participants and ítems were random effects.

The main-effects-only model ($Model_{Main}$) is preferred over the full model: $BF_{M,F}$ = 160, meaning that given the data, the main-effects-only model is 160 times more likely than the full model (main effects plus interaction). The main-effects-only model is also preferred over the grade-only model: $BF_{M,G}$ = 1e+ 06.

When we compare $Model_{Main}$ with $Model_{Prime=50ms}$, the latter is preferred. Simply put, this model assumes that the priming effect is a 50-ms savings in every identity primed trial: $BF_{50,M}$ = 42.

Accuracy data

The results from the accuracy analyses are straightforward. As can be seen in Table 1, participants were quite accurate (on average, even second graders had accuracies over .90 for both words and nonwords).

For word trials, the preferred model was $Model_G$ because older children have higher accuracies, whereas there seems to be no effect of prime type on accuracy: $BF_{G,M}$ = 613. Furthermore, if we compare $Model_G$ with an entirely null model as the denominator (i.e., a model in which there are no effects other than the random effects of item and participant), the Bayes factor is $BF_{G,0}$ = 37. For nonword trials, the preferred model was the null model with Bayes factors $BF_{0,G}$ = 8.8 and $BF_{0,M}$ = 5415.

Distributional analyses

In mental chronometry studies, an examination of RT distributions is often done by computing the RTs at specific quantiles and then, if there are critical conditions to be compared, by analyzing the quantile–quantile residuals. One of these methods is called delta plots (see Ridderinkhof, 2002). Delta plots display the RT difference between two experimental conditions as a function of processing time. The four hypotheses described in the Introduction make differential predictions on the delta plots. Illustrations with simulated data are shown in the upper panels of Fig. 2:

- *Priming provides an encoding head start.* The effect of masked priming would be a shift in the RT distribution numerically identical to the prime–target SOA; hence, according to this hypothesis, the delta plot should be flat with an intercept of 50 ms.
- *A head start, but with a different size than the SOA.* The delta plot is flat, but with an intercept different from the prime–target SOA.
- *The priming effect may reveal differences in the decision process.* In developing children, the effects of priming cascade beyond the encoding process into the decisional component; hence, not only is there a shift in the delta plot, but also the differences between the identity and the unrelated conditions are larger for the slower responses than for the faster responses. Therefore, the delta plot begins at near 50 ms but has a positive slope and grows for higher quantiles.

The lower panels of Fig. 2 (second grade and fourth grade) show the empirical delta plot comparing the RT distributions for related and unrelated primes. The priming effects are best described as a flat line around 50 ms for both age groups. It is worth discussing the dip in the final quantile in the empirical delta plots for both age groups; we believe that the dip in the .90 quantile is due to slow responses being contaminated by distraction—which would reduce the priming effect.

Diffusion model fit

The presented results show a fairly clear picture of the effects of priming as a shift in the RT distribution. Furthermore, this shift is about the same size in second and fourth graders. We fit the diffusion model (see Ratcliff et al., 2004) to the averaged data. The goal of this fit is to implement the savings in encoding hypothesis in the context of a well-established model and to confirm that this implementation provides a good account of the empirical data.

For each participant and each condition, the RTs at the .10, .30, .50, .70, and .90 quantiles were calculated for "word" responses (recall that this was a go/no-go lexical decision experiment). Then, these RTs at quantiles were averaged across participants of the same grade level. The response probabilities were also averaged across all participants for each grade. The fitting routine aims to minimize the difference between the predicted and empirical proportions of responses within a time bin (see Ratcliff & Tuerlinckx, 2002).

Table 1
Descriptive statistics for all conditions.

Lexicality	Relation	Case match	Mean RT (ms)	SE_{RT}	Mean accuracy	$SE_{Accuracy}$
Grade 2						
Pseudowords	Identity	Match			.932	.0063
Pseudowords	Identity	Mismatch			.935	.0062
Pseudowords	Unrelated	Match			.920	.0068
Pseudowords	Unrelated	Mismatch			.952	.0054
Words	Identity	Match	1090	12	.910	.0072
Words	Identity	Mismatch	1097	12	.919	.0068
Words	Unrelated	Match	1127	11	.894	.0077
Words	Unrelated	Mismatch	1171	12	.929	.0064
Grade 4						
Pseudowords	Identity	Match			.948	.0075
Pseudowords	Identity	Mismatch			.945	.0077
Pseudowords	Unrelated	Match			.941	.0079
Pseudowords	Unrelated	Mismatch			.958	.0068
Words	Identity	Match	911	13	.976	.0052
Words	Identity	Mismatch	906	13	.972	.0056
Words	Unrelated	Match	953	12	.968	.0059
Words	Unrelated	Mismatch	942	12	.970	.0057

Note. The presented standard errors are calculated across participants. RT, response time.

Given the empirical findings, we decided to allow all parameters to vary between the two age groups, and the T_{er} parameter to vary as a function of the prime–target relationship. Notably, the T_{er} parameter for second graders went from .831 s for unrelated primes to .769 s for identity primes (a .062-s effect), whereas the T_{er} parameter for fourth graders went from .534 to .486 (a .048-s effect); note that both values[2] are very close to the .054-s effect in T_{er} reported by Gomez et al. (2013).

Discussion

The main goal of this research was to examine whether masked identity priming in developing readers (second graders and fourth graders) can be modeled as a savings effect (i.e., where an identity prime would enjoy an encoding advantage over an unrelated prime; Forster, 1998) (note that this is the case in adult readers; Gomez et al., 2013). Although the masked priming technique has become a common tool used to examine the early moments of word reading in children, there is a gap in the literature as to whether the nature of the processes underlying masked priming differ from those in adult readers. We conducted a masked identity priming experiment with second- and fourth-grade students in which we manipulated the prime–target relationship in two ways: case match versus mismatch (for identity pairs) and unrelated primes versus identity primes.

The effect of case matching (e.g., arte–ARTE vs. ARTE–ARTE) was null. Targets always were presented in uppercase, yet the case of primes did not affect the RT or accuracy; there was an invariance between case-matched and case-mismatched trials even in the youngest group of readers. This supports the idea that as early as second grade, readers can encode to the orthographic representation for letters during the first moments of word processing, as tracked by masked identity priming (see Jackson & Coltheart, 2001).

Furthermore, the empirical and modeling results support the hypothesis of masked identity priming tapping into the same underlying mechanisms in second and fourth graders. Masked identity priming produces a shift in the RT distribution regardless of the grade of the participants; this shift is remarkably similar for the two age groups (50 ms). As predicted by Forster's (1998) savings hypothesis, the magnitude of this shift is similar to the prime–target SOA. This was so despite the fact that the

[2] Other parameters of the model are as follows: for second graders: a = .138, z = 0.05, sz = 0.025, drift for words = 0.136, drift for nonwords = −0.143, eta = .010, st = 0.241, $p0$ = .003; for fourth graders: a = .151, z = 0.05, sz = 0.093, drift for words = 0.253, drift for nonwords = −0.258, eta = .092, st = 0.008, $p0$ = .0003.

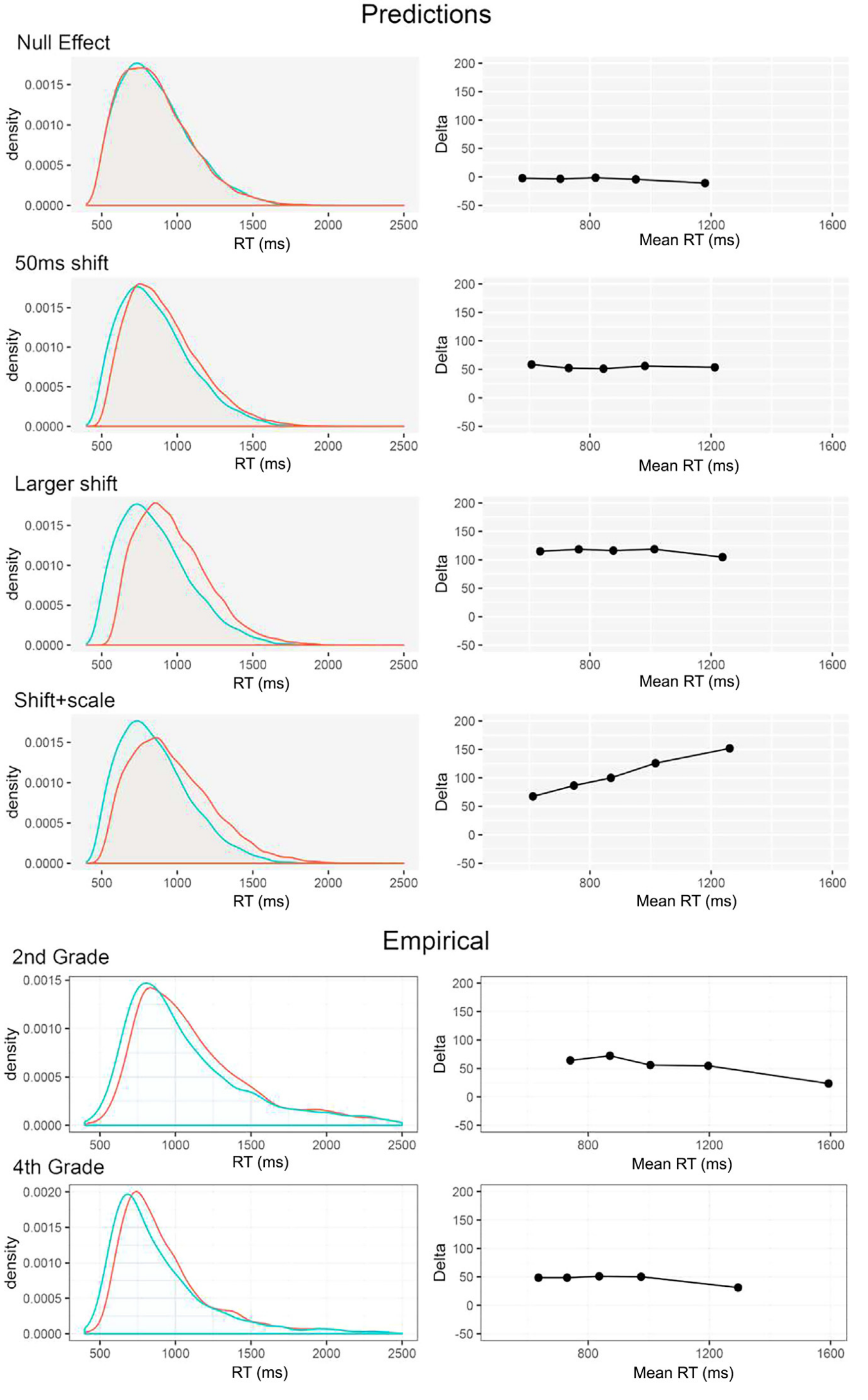

Fig. 2. The upper panels represent the predictions of the four hypotheses under consideration. Within each panel, the graph on the left side shows the response time (RT) distribution, and the graph on the right side is the corresponding delta plot. The lower panels show the empirical Vincentized RT distributions and the delta plots for second and fourth graders.

overall RTs were much larger and noisier for second graders. Given the straightforward nature of the data, it is not surprising that the Bayes factors, delta plots, and diffusion model fits all provide converging evidence in favor of the same hypothesis. Our approach here was to explore the most tractable form of masked priming—identity priming with no further lexical, semantic, or morphological manipulations. Future research should explore this issue along with other types of prime–target relationships and word frequency (see Forster & Davis, 1984: Grainger, Lopez, Eddy, Dufau, & Holcomb, 2012).

To conclude, we emphasize the theoretical and practical implications of our findings. From the theoretical point of view, we reaffirm the idea that masked identity priming can be viewed as a head start in the encoding process (Forster, 1998). Such an encoding process is orthographic, not sensory, given that masked identity priming is not modulated by the match–mismatch between the letter case of primes and targets in second- and fourth-grade readers (see also Forster, 1998; Perea, Vergara-Martínez, & Gomez, 2015, for parallel evidence with adult readers). Within a drift diffusion model, this is captured by the T_{er} parameter. This parameter is assumed to be related to encoding processes that translate the perceptual information into the evidence that is accumulated in the decision process (see Brown & Heathcote, 2008, for a similar parameter within other forms of evidence accumulation models).

A corollary of our study is a warning about transformations of RT data in developmental studies. For this, we refer back to Fig. 1. There are two main patterns of results that occur in latency-based tasks in cognitive psychology: (a) distributional shifts and (b) changes in the shape of the distribution. In this study, the masked identity priming effect produced a shift, whereas age of readers changed the shape of the distribution, with smaller variance in the RTs of fourth graders. If we transformed the data scaling by variance (or standard deviation), we would find an interaction between age and priming. Our process model guides our decision not to transform the data, and we encourage researchers to consider their processing assumptions as they decide to transform or not transform their data (see, e.g., Faust, Balota, Spieler, & Ferraro, 1999, for a discussion of when transforming is advisable).

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Appendix A. List of words and pseudowords in the experiment

Words: DEDO, DEJA, CAER, CERA, RATA, ALTA, BATA, BAÚL, TELE, LEÑA, UNIR, CIEN, VINO, SEIS, VIVA, CINE, CASI, MIMO, SUMA, VIVO, ALGA, ANDA, PEGA, AMAR, ARTE, EDAD, GIRA, REJA, ARMA, OLER, CITA, BICI, KIWI, MISA, CUNA, IMÁN, CIMA, NUCA, MINA, IRIS.

Pseudowords: EDGA, REVA, DAKE, WEDE, MEER, DERU, EMAB, EGTE, BAME, AMEG, VUME, NUVO, ITÉN, BITU, TISE, CISE, MISE, NAIS, CEVI, CONU, ETDA, CEHE, BEÑE, GIAL, ERED, EBTA, BIRE, GAJE, ELMA, OBAR, VUCA, MUWI, CUVE, ETUC, IVIR, CUEK, NIME, NOCE, NITE, ORIM.

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2020.104911.

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