Cognitive Development 24 (2009) 80–87

Contents lists available at ScienceDirect

Cognitive Development

Short report

Opposing effects of age and reading ability on pseudoword priming

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ARTICLE INFO

Keywords:
Priming
Memory development
Reading ability
Pseudowords

ABSTRACT

Repetition priming refers to the facilitation of stimulus processing due to prior processing of the same or similar stimulus, and is one of the most primitive ways in which experience and practice can affect performance. Previous studies have produced contradictory results regarding the stability of repetition priming across development. Drawing on models of word priming that suggest decreased priming with increased reading ability, the present experiment investigated the possibility that null effects of age in priming are due to opposing effects of age and reading ability on priming magnitude. Forty-eight participants between 7 and 22 years old read aloud primed and unprimed pseudowords, after completing a reading ability assessment. In line with predictions, the magnitude of priming for pseudowords increased with increased age when reading ability was controlled, and decreased with increased reading ability when age was controlled. Moreover, neither the age nor ability effect was significant when tested without the other. Results were not influenced by explicit memory for primed pseudowords. Thus, the present experiment provides evidence for developmental increases in word priming, as well as a potential explanation for the lack of developmental effects in previous studies.

Central to most theories of learning is the idea that experience and practice improve performance. One type of learning, referred to as repetition priming, occurs when prior processing facilitates subsequent processing of the same or similar stimuli (for reviews, see Roediger & McDermott, 1993; Schacter & Tulving, 1994). Unlike other forms of learning priming occurs automatically, often without awareness or intention, and does not require explicit practice or encoding/retrieval strategies. Some have argued

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0885-2014/$ – see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.cogdev.2008.08.002

that priming reflects a primitive type of learning that, once established, is relatively stable throughout development (Schacter & Moscovitch, 1984; Squire, 1987; Tulving & Schacter, 1990). Supporting this perspective, several researchers have observed little or no change in priming magnitude in participants from 5-year-olds to young adults (Billingsley, Smith, & McAndrews, 2002; DiGiulio, Seidenberg, O'Leary, & Raz, 1994; Drummey & Newcombe, 1995; Hayes & Hennessy, 1996; Naito, 1990; Perez, Peynircioglu, & Blaxton, 1998; Russo, Nichelli, Gibertoni, & Cornia, 1995). Contrary to this perspective, however, others have observed increased priming with increased age across similar age groups (Alario, De Cara, & Ziegler, 2007; Booth, Perfetti, & MacWhinney, 1999; Cycowicz, Friedman, Snodgrass, & Rothstein, 2000; Kang & Simpson, 1996; Komatsu, Naito, & Fuke, 1996). Thus, the view that repetition priming is unaffected by development is not without controversy.

Several hypotheses have been proposed to explain these discrepant findings. Some researchers have argued that increased priming with age is due to influences from explicit memory (Parkin & Streete, 1988; Russo et al., 1995). For example, during a picture fragment completion task, Russo et al. (1995) observed increased priming with increased age in an initial analysis including all of their stimuli. However, after removing the stimuli that participants explicitly recalled from the analysis, the increase in priming with age disappeared, leading them to conclude that priming is stable across development when explicit retrieval strategies cannot be employed. The influence of explicit memory on priming cannot explain all developmental effects, however, because others have observed increased priming with age, even after removing explicitly recalled items from the analysis (Cycowicz et al., 2000).

Other researchers have suggested that developmental effects in priming may be obscured by different levels of baseline performance in different aged participants (Cycowicz et al., 2000; Komatsu et al., 1996). That is, high levels of baseline performance may restrict the amount of facilitation observable as a consequence of priming, while lower levels may enhance it. Increased priming with age thus may be concealed by higher levels of baseline performance in older participants. Direct support for this idea comes from a study of word fragment completion priming in which increased priming with age was observed when baseline differences were corrected, but equivalent priming with age was observed when they were not (Komatsu et al., 1996). Critically however, correcting for baseline differences only revealed increased priming with age when words were generated during the encoding phase. When words were read during the encoding phase, priming did not vary with age even when baseline differences were corrected (Komatsu et al., 1996). Thus, baseline differences cannot account for all instances of equivalent priming across age groups.

Models of word priming that highlight the role of reading ability provide another possible explanation for inconsistent developmental effects in priming studies (Booth et al., 1999; Plaut & Booth, 2000; Plaut, McClelland, Seidenberg, & Patterson, 1996; Stark & McClelland, 2000). In particular, these models emphasize the compression of priming effects at high levels of reading ability. That is, due to limits on the system's processing efficiency, high-ability readers, who are maximally efficient at word processing, do not benefit from priming to the same extent as lower-ability readers, who have not achieved maximum efficiency (Plaut & Booth, 2000; Stark & McClelland, 2000). This idea is similar to the aforementioned baseline-differences perspective in that it is based on underlying performance differences. However it suggests that priming is a non-linear function of reading ability, which cannot be removed through any corrective formula. It is thus possible that negative effects of reading ability on word priming cancel out positive effects of age in studies including expert readers, such as college undergraduates. Indeed, developmental studies of word priming that include college undergraduates have observed equivalent priming across age groups (Castles, Davis, & Letcher, 1999; Naito, 1990), whereas studies confined to children have observed increased priming with age (Booth et al., 1999; Kang & Simpson, 1996). Nonetheless, few word priming studies have measured reading ability directly, and those that have measured reading ability have not obtained measurements from expert readers (Alario et al., 2007; Booth et al., 1999). Thus, the relationship between priming, age, and reading ability is unclear.

To test these relationships, the present study examined the effects of age and reading ability on priming magnitude during a pseudoword reading task in a group of 7–22-year-old participants. Pseudowords, rather than real words, were used in order to increase task difficulty and hence priming magnitude for the high-ability readers (Stark & McClelland, 2000). In addition, explicit memory for primed pseudowords was measured in a forced-choice, recognition-memory paradigm, to control for the potential influence of explicit memory on priming effects (Parkin & Streete, 1988; Russo et al., 1995).

1. Method

1.1. Participants

Forty-eight participants (22 male; mean age 15.38 years; range 7–22) from a university community and surrounding area completed the study. Younger participants were compensated $10. Older participants received partial credit in university psychology courses. All participants were native speakers of English, had normal or corrected-to-normal vision, and no known psychological or neurological deficits.

1.2. Materials

Stimuli were 148 pseudowords derived from 148 real words in the English language. Real words were 3–5 letters in length (average = 4.1), monosyllabic (88%) or disyllabic (12%), and of relatively high frequency in the language (average = 750 occurrences per million; range = 195–10,595; Kucera & Francis, 1967). Pseudowords were created by changing one of the letters in each of the real words, such that they were easily pronounceable according to English pronunciation rules, but did not have meaning or usage in the English language (e.g. *long* was changed to *lonk*). The 148 pseudowords were divided into 4 lists of 37 items each, equated for average length, number of syllables, and corresponding real-word frequency. Counterbalancing was achieved by rotating these lists across conditions and participants.

Pseudowords were presented in white, 36-point, Helvetica font against a black background on a 21-in. CRT monitor, and subtended ~1.5°–3° horizontally and 1° vertically of visual angle. A chin rest was employed to keep participants' eyes approximately 30 in. from the monitor. Stimulus presentation was controlled by the PsyScope software package (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants' verbal responses were recorded through a microphone connected to a digital voice recorder.

1.3. Procedure

Participants were tested individually in sessions that lasted approximately 45 min. At the beginning of the session, a measure of the participant's reading ability was obtained using the word identification, word attack, and passage comprehension subtests of the Woodcock Reading Mastery Test – Revised (Woodcock, 1987). The average of the weighted scores from the three subtests was used as the measure of each participant's reading ability.

Immediately after the reading assessment, participants engaged in the encoding phase of the experiment. During this phase, participants read aloud 74 pseudowords (plus 3 at the beginning and end, to attenuate primacy and recency effects). Pseudowords were presented one at a time for 2.5 s each at a rate of 1 per 5 s. A fixation cross (+) preceded each presentation and remained on the screen between stimulus trials. Half of the pseudowords (37 items) were presented in all lowercase letters, and half were presented in all uppercase letters. This encoding phase lasted approximately 6.5 min.

After the encoding phase, participants were permitted a short break (~1 min) before beginning the test phase. During the test phase, participants read aloud 111 pseudowords (plus 5 at the beginning, to accustom them to the faster presentation). Pseudowords were presented one at a time for 200 ms at intervals of 2.5, 5, and 7.5 s (average rate of 1 per 5 s). A fixation cross preceded each presentation and remained on the screen between stimulus trials. Pseudowords were presented in all uppercase letters at test. One third of the test items (37 items) had been presented during the encoding phase in uppercase letters (same letter-case primed items); one third of the test items had been presented during the encoding phase in lowercase letters (different letter-case primed items); one third of the test items had not been presented previously (unprimed items). The test phase lasted approximately 9 min.

Participants were instructed to read pseudowords aloud as quickly and accurately as possible during the encoding and test phases of the experiment. No reference to a subsequent test phase was made during the encoding phase, and no reference to the prior encoding phase was made during the test phase.

Immediately after the test phase, participants engaged in a recognition-memory test. A series of 74 pseudowords were presented one at a time, and participants pushed a key on the computer keyboard to indicate whether or not they had seen that word during either of the previous phases. The pseudoword remained on the screen until the participant responded. An inter-stimulus interval of 1 s occurred between the participant's response and the onset of the next trial. Half of the pseudowords were same letter-case primed items from the test phase (old items), and half had not been seen previously during either phase (new items).

2. Results

Errors and reaction times for correct responses were extracted from digital recordings of the test phase for each participant. Because errors were occasionally difficult to judge, two research assistants, blind to the conditions of the study, scored each participant's responses. Items were coded as errors when they were judged to be incorrect independently by both research assistants. Disagreement between coders occurred on less than 2% of the trials. Reaction times for correct responses were measured using ASSERT, a threshold-based, reaction time detection program (Nelles et al., 2003). Preliminary analyses assessing the effect of letter case (same vs. different letter-case primed) did not reveal significant differences between the two conditions in error rates or response times. Thus, same and different letter-case primed items were collapsed into a single "primed" condition for the present analyses.

"Old" and "new" responses during the recognition-memory phase were determined from key presses recorded by PsyScope (Cohen et al., 1993), and transformed to an estimate of sensitivity (d_L) for each participant, according to a signal-detection model based on logistic distributions (Snodgrass & Corwin, 1988). For this transformation, proportions of 0 and 1 were converted to $1/(8N)$ and $1-(1/[8N])$, respectively, where N was the number of items in the condition (37).

Overall performance on the priming and recognition-memory tasks was first examined without considering individual variation. Priming was assessed via paired t-tests comparing primed and unprimed items with respect to response times and error rates separately. Priming was observed in response times, with primed items being read more quickly (662 ms) than unprimed items (682 ms), $t(47) = 4.53$, $p < .001$. No priming was observed in the error rates, which were low (<10%), $t < 1$. Explicit memory was assessed by a one-way t-test assessing sensitivity (d_L). Sensitivity ($d_L = 3.41$) differed significantly from 0, $t(47) = 12.93$, $p < .001$, indicating that explicit memory was present.

Individual variation in priming was examined via multiple-regression analyses of "prime scores." "Prime scores" were based on response times only, since priming was not observed in the error rates, and were computed by subtracting the primed response time from the unprimed response time and dividing by the unprimed response time. The difference between primed and unprimed was proportionalized in this manner in order to correct for baseline differences across participants (Cycowicz et al., 2000; Komatsu et al., 1996; Snodgrass, 1989). This was especially important for the present dataset in which overall speed and reading ability were positively correlated, $r = .412$, $p = .003$. Prime scores were then analyzed in a model including age (in years to the 100th decimal place), reading ability (as assessed by the Woodcock Reading Mastery Test), sensitivity (d_L), and gender (male = -1; female = 1), as independent variables. Gender differences have been reported in aspects of cognition that may influence pseudoword priming, such as verbal processing (Maccoby & Jacklin, 1974), production (Halpern, 1997), and certain types of memory (Guillem & Mograss, 2005; Voyer, Postma, Brake, & Imperato-McGinley, 2007). Accordingly, gender was included as an independent variable to control for its potential influence.

Together these variables accounted for a small, but significant, portion of the variance in prime scores, $R^2 = .199$, $F(4, 43) = 2.67$, $p = .045$. In line with models of word priming (Plaut & Booth, 2000; Stark & McClelland, 2000), priming magnitude decreased with increased reading ability, ß = $-.461$, $t(43) = -2.41$, $p = .020$. Furthermore, in line with previous developmental priming studies (Cycowicz

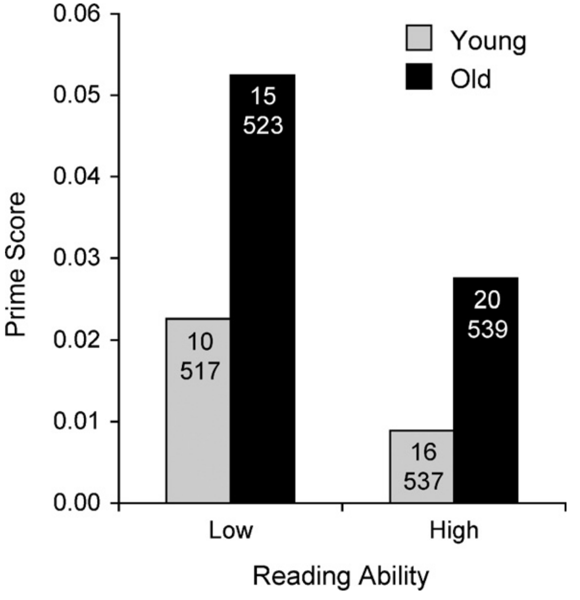

Fig. 1. Illustration of the opposing effects of age and reading ability on prime scores during the pseudoword reading task. Numbers on the bars refer to the mean age (in years) and mean reading ability (based on scores from the Woodcock Reading Mastery Test – Revised (Woodcock, 1987; see text for details) of participants within each group. Note that age and reading ability were continuous variables in multiple-regression analyses and that graph is for illustrative purposes only.

et al., 2000), priming magnitude increased with increased age, ß = .391, $t(43) = 2.11$, $p = .041$. Critically, prime scores were not related to sensitivity in isolation, $r = -.004$, $p = .979$, or when controlling for the other variables, ß = −.020, $t(43) = -.115$, $p = .909$; thus increased explicit memory with age did not affect the priming results (Parkin & Streete, 1988; Russo et al., 1995). Finally, although females exhibited slightly greater prime scores than males, the effect of gender on priming was not significant.

To further assess these relationships, the effects of age and reading ability on prime scores were entered into the model sequentially. Not surprisingly, given the opposing effects of the variables on priming and their high positive correlation ($r = .634$, $p < .001$), neither age nor reading ability accounted for a significant portion of the variance in prime scores when entered without the other, both *ps* > .148. In line with the above results however, each variable increased the overall predicted variance in the model significantly when entered at the second step, $F_{[age]}(1, 43) = 4.46$, $p = .041$, $F_{[ability]}(1, 43) = 5.85$, $p = .020$.

The opposing effects of age and reading ability on priming magnitude are illustrated in Fig. 1. For this graph, data were median split by age, and within age, by reading ability, and plotted as a function of the two variables. Note that priming is greater for older than younger participants in both the low and high reading-ability groups, but that overall priming is greater in the low than high ability group.

3. Discussion

Previous studies have produced contradictory results regarding the stability of repetition priming across development. Drawing on models of word priming that suggest decreased priming with increased reading ability (Plaut & Booth, 2000; Stark & McClelland, 2000), the present experiment examined the possibility that null effects of age in word priming experiments are due to opposing effects of age and reading ability on priming magnitude. Results support this hypothesis. The magnitude of priming for pseudowords increased with increased age when reading ability was controlled, and decreased with increased reading ability when age was controlled. Moreover, neither the age nor ability effect was significant when tested without the other. Thus, results provide evidence for developmental increases in word priming, as well as a potential explanation for the lack of developmental effects in previous studies.

The priming results in the present experiment were not influenced by explicit memory for pseudowords. That is, priming magnitude did not vary with explicit memory in isolation or when controlling for the other variables, and the effects of age and reading ability on priming were significant after controlling for explicit memory. This is a valuable observation given that previous studies have observed increases in explicit memory with development (Billingsley et al., 2002; Cycowicz et al., 2000; DiGiulio et al., 1994; Drummey & Newcombe, 1995; Hayes & Hennessy, 1996; Mecklenbräuker, Hupbach, & Wippich, 2003; Naito, 1990; Perez et al., 1998; Russo et al., 1995), and that explicit memory may influence priming magnitude under certain conditions (Parkin & Streete, 1988; Russo et al., 1995). Importantly, it did not in this study.

Clearly age and reading ability are closely related, as the majority of literate individuals learn to read during childhood. Indeed, it was the strong relationship between these factors (and their opposing influences on priming) that resulted in null effects of age on pseudoword priming when reading ability was not controlled in the present study. Less clear, however, is how the relationship between age and ability might affect priming during less lexical tasks, such as picture-fragment completion and picture naming—tasks that, like word priming, have produced contradictory age effects (Billingsley et al., 2002; Cycowicz et al., 2000; Drummey & Newcombe, 1995; Hayes & Hennessy, 1996; Murphy, McKone, & Slee, 2003; Perez et al., 1998; Russo et al., 1995). Like reading ability, abilities associated with efficient picture identification increase with age (Bova et al., 2007). Therefore, increasing effects of age may be canceled out by decreasing effects of ability in picture priming studies. It is also possible that priming in picture naming is not affected by age, even when controlling for ability, since object recognition skills develop much earlier than reading skills. Future studies examining different types of priming while controlling for ability in the relevant domain could help determine whether increased priming with age is specific to reading and word/pseudoword priming or a more general property of development.

Evidence for increased priming with age in the present study contradicts theories emphasizing the stability of implicit memory throughout development (Schacter & Moscovitch, 1984; Squire, 1987; Tulving & Schacter, 1990). Nonetheless, increased priming with development is not surprising given the many cognitive and neurobiological changes that occur during childhood and adolescence. For example, greater selective attention and inhibitory control in older than younger participants (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Casey et al., 1997; Davis, Bruce, Snyder, & Nelson, 2003; Jonkman, 2006; Ridderinkhof, van der Molen, Band, & Bashore, 1997; Williams, Ponesse, Schachar, Logan, & Tannock, 1999) could lead to more effective stimulus encoding, which may in turn lead to greater priming in older participants. In addition, greater myelination in older than younger participants (Barnea-Goraly et al., 2005; Courchesne et al., 2000; Giedd et al., 1999; Pfefferbaum et al., 1994; Sowell et al., 1999) could lead to greater modification of representations and hence greater priming. These possibilities and others await future experiments.

Acknowledgments

Support for this research was provided by the Social Sciences Division at Rice University. Thanks are owed to Elyse Aurbach, Sharon Ho, Nancy Lin, and Rijuta Pandav for assistance with data collection and scoring, to David Lane for help with statistical analyses and interpretation, and to Chad Marsolek for useful comments and discussion.

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