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Phonological Coding During Reading

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The exact role that phonological coding (the recoding of written, orthographic information into a sound based code) plays during silent reading has been extensively studied for more than a century. Despite the large body of research surrounding the topic, varying theories as to the time course and function of this recoding still exist. The present review synthesizes this body of research, addressing the topics of time course and function in tandem. The varying theories surrounding the function of phonological coding (e.g., that phonological codes aid lexical access, that phonological codes aid comprehension and bolster short-term memory, or that phonological codes are largely epiphenomenal in skilled readers) are first outlined, and the time courses that each maps onto (e.g., that phonological codes come online early [prelexical] or that phonological codes come online late [postlexical]) are discussed. Next the research relevant to each of these proposed functions is reviewed, discussing the varying methodologies that have been used to investigate phonological coding (e.g., response time methods, reading while eye-tracking or recording EEG and MEG, concurrent articulation) and highlighting the advantages and limitations of each with respect to the study of phonological coding. In response to the view that phonological coding is largely epiphenomenal in skilled readers, research on the use of phonological codes in prelingually, profoundly deaf readers is reviewed. Finally, implications for current models of word identification (activation–verification model, Van Orden, 1987; dual-route model, e.g., M. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; parallel distributed processing model, Seidenberg & McClelland, 1989) are discussed.

Keywords: phonological coding, reading, inner voice, lexical access, language comprehension

When we read silently, we experience the sensation of "hearing" the words of the text in our head. This *inner voice* is a subjective manifestation of phonological coding, the recoding of orthographic (written) information into phonological (sound) information. Exactly why this recoding occurs and what the nature of this recoded information is are still debated, despite over a century of research on the topic (for an earlier review, see McCusker, Hillinger, & Bias, 1981). Although the specific questions of interest have changed over time, common themes underlie all investigations on the topic: What exactly is the nature of the inner voice, and what purpose does it serve? In this review, the focus is mainly on a discussion of its purpose, with some insights from the nature of the inner voice where applicable.

Although divisions of opinions are not perfectly clear-cut, there are generally three proposed roles for phonological coding during reading: (a) that phonological codes are generated early and (possibly) implicated in the process of lexical access (accessing the meaning of a word); (b) that phonological codes come online as a function of lexical access or after lexical access and serve to bolster short-term memory, aid in comprehension, and restore prosody and intonation to the memory trace; and (c) that phonological codes are a byproduct of the reading instruction process and are largely epiphenomenal in the skilled adult reader. Each of these possibilities is explored along with the data that have been used to support them.

Much of the disagreement may stem from ambiguity as to whether these proposed functions are subserved by the same phonological codes, or whether there may in fact be multiple phonological codes supporting different functions and varying in the extent to which each resembles overt speech. Indeed, the process referred to as phonological coding has gone by several names (e.g., subvocalization, inner speech, phonological recoding, speech recoding, etc.), with no consistent mapping between a given name and a proposed function—meaning that some differences of opinion in the literature may actually have arisen because the processes under investigation were different, even though in name they were the same.

When Does Phonological Coding First Begin?

Although our ultimate goal is to understand the function(s) of phonological coding and the inner voice, before we can really talk about what phonological coding is doing, we need to know when it comes online. If, for example, we find evidence that phonological coding does not come online until after a word has been accessed in the lexicon, then phonological coding cannot underlie lexical access. On the other hand, simply finding that phonological codes are activated prelexically does not necessarily implicate

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them in the lexical access process. It is therefore essential to review findings on the time course of phonological coding and the role of phonological coding in tandem to gain a complete picture of its normal function in the silent reading process. Unfortunately, previous research exploring these two questions has resulted in discrepant and often mutually exclusive conclusions, leading some researchers to conclude that phonological codes don't come online until relatively late and are used only to a limited extent by skilled adult readers (e.g., Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Waters, Komoda, & Arbuckle, 1985; Waters, Seidenberg, & Bruck, 1984) and others to conclude that phonological codes come online very early and are in fact the primary means by which readers achieve lexical access (e.g., Lukatela & Turvey, 1994a, 1994b; Van Orden, 1987).

Among theories positing an early role for phonological coding during reading, there are two main ways in which the code is proposed to come online: Either phonological codes are rapidly generated from grapheme to phoneme mapping rules (*assembled phonology*) or phonological information is rapidly accessed from the lexicon through the orthographic representation of the printed word (*addressed phonology*). The former route is one in which phonological codes are generated prelexically and can in fact aid lexical access; the latter route is a direct mapping from orthography to the lexical entry and phonological codes can only come online once the correct lexical entry has been accessed and the associated phonological representation retrieved.

Specific models of lexical access also vary in the extent to which they support these different routes to phonology during lexical access. Although it is beyond the scope of the current article to give a full account of the many models of single word reading comprehension, a few of the most influential models are discussed as they relate to the question of phonological coding during reading. First, the activation–verification model, or phonological mediation model (Van Orden, 1987), supports the rapid role of prelexical assembled phonology during reading, and proponents of the model claim strongly that a word's phonology is "the initial and primary code by which a word accesses its representation in the internal lexicon" (Lukatela & Turvey, 1994b, p. 333). According to this model, phonological codes are assembled rapidly and serve as an early source of constraint on the visual recognition of printed words. This two-stage model posits early activation of a word's phonological code (assembled phonology), which is used to activate candidate lexical representations, followed by a cleanup process whereby incorrect representations are suppressed once the phonologically retrieved (addressed) spelling is matched to the orthographic form information. This model, then, claims that the normal reading process relies heavily on assembled phonology to achieve lexical access and that addressed phonology is only used in the later verification stage.

On the other hand, the dual-route model (M. Coltheart, 1978, 1980; M. Coltheart, Curtis, Atkins, & Haller, 1993; M. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) supports either an assembled phonological route or a direct orthographic route as a potential way of arriving at a written word's lexical entry. Proponents of the dual-route model assume that the direct route is more efficient and therefore serves as the predominant route used by skilled adult readers (e.g., M. Coltheart, 1980). The assembled phonological route then is used by less skilled, beginning readers or by skilled readers when encountering a novel word for which the more direct, addressed route is not yet established (Doctor & Coltheart, 1980). Under this view, skilled readers do not necessarily generate prelexical phonological codes when reading for meaning.

Last (in the scope of this review) is the connectionist model of Seidenberg and McClelland (1989). Their parallel distributed processing model of visual word recognition is also a dual-route model in that it posits direct links from orthography to meaning representation and also from orthography to phonology (and on to meaning). The assumption is that by default during normal skilled reading, semantic representations are activated directly from orthography but phonological codes are being activated in parallel, resulting in a phonological code that becomes available and can in fact influence performance regardless of whether it is necessary for the task. Importantly, this model allows for the generation of phonological codes prelexically, without meaning access being phonologically mediated.

What this brief overview of the models of lexical access demonstrates is the range of opinions on the role of phonological coding during reading. On one extreme, the activation–verification model (Van Orden, 1987) asserts that phonological coding is necessarily occurring during reading, as assembled phonology serves to activate candidate lexical entries in the lexicon. On the other end of the spectrum, the dual-route model (e.g., M. Coltheart, 1980) posits that phonological coding is used to access unfamiliar words (which are all words for beginning readers) but that a direct route from orthography to meaning is used by skilled readers—meaning that phonological coding is largely not implicated in lexical access. Falling somewhere in between is the parallel distributed processing model (Seidenberg & McClelland, 1989) in which both routes to meaning are engaged in parallel, such that phonological codes are always generated but are not always used to achieve lexical access.

Considering the large amount of data that have been collected on phonological coding during reading, it is surprising that models with such varying views on the role of phonological coding can exist. One possibility is that the issue is a methodological one—that certain methodologies result in data that support a role for phonological coding during lexical access and others result in data that seem to support direct access and little to no phonological coding. As such, this review focuses on the different methodologies that have been used to study the time course of phonological coding, asking what evidence each method provides and what can actually be concluded based on that evidence.

Evidence From Response Time Methods and Nonreading Tasks

Naming. To determine when phonological codes first come online and are used by the language processing system, the questions of interest are whether phonological codes are generated prelexically and, if so, whether they are then used to achieve lexical access during word identification. One method that has been used to ostensibly investigate the process of lexical access is to have subjects name written words aloud. Coupling the naming task with a priming paradigm, where phonological overlap between the prime and target is manipulated, has been used to assess the early activation of phonological codes (e.g., Drieghe & Brysbaert, 2002; Lesch & Pollatsek, 1993; Lukatela, Lukatela, & Turvey, 1993; Lukatela & Turvey, 1994a, 1994b). Using this phonological priming during naming paradigm, Lukatela and Turvey (1994b) found that a homophone prime (TOWED) and pseudohomophone prime (TODE) facilitated the naming of a target word (*toad*) at stimulus onset asynchronies (SOAs) as short as 30 ms.

Rather than using phonological priming, others have used associative priming in a naming task and incorporated a phonological manipulation. Lesch and Pollatsek (1993) had subjects perform a naming task with associates (e.g., *beach*), homophones of the associates (e.g., *beech*), orthographic controls (e.g., *bench*), and unrelated controls (e.g., *fluid*) presented as primes for the to-be-named target (*sand*). They varied the duration of prime presentation and found that at short SOAs (e.g., 50 ms) the target was responded to faster following the associate prime as well as the homophone of the associate, whereas there was no benefit of the orthographic control, supporting the claim that phonological codes begin to come online very early (within 50 ms) and in fact may have an earlier influence on lexical access than orthography. At longer SOAs (e.g., 200 ms), priming from the homophone was reduced, whereas priming from the associate remained significant, suggesting, according to Lesch and Pollatsek, that the spelling verification process had completed by 200 ms and that any phonologically activated lexical representations whose orthography did not match the addressed spelling had been suppressed. Lukatela and colleagues replicated (Lukatela et al., 1993) and expanded (Lukatela & Turvey, 1994a) the results of Lesch and Pollatsek (1993) by including pseudohomophones of the associate as an additional condition. They found that the pseudohomophones facilitated naming at both the short (50 ms) and long (250 ms) SOAs and explained that, as nonwords, the pseudohomophones would not activate their own lexical entry (with an associated orthographic representation) in the same way that homophones do, and therefore are not subject to suppression during the verification/cleanup stage. Drieghe and Brysbaert (2002) found this same pattern of results in a Dutch replication, demonstrating that the early activation of phonological codes in lexical access is not specific to English but rather is observed in the processing of other alphabetic languages as well.

In general, then, the naming results seem to support an early role for prelexical phonology, such that homophone and pseudohomophone primes show facilitatory effects at SOAs as short as 30–60 ms. However, there are a few criticisms to be made of using naming to assess whether phonological codes are generated prelexically and furthermore whether they are used in silent reading for meaning. First, since the naming task requires the subjects to produce the word aloud, it requires that the subjects activate phonological information and may in fact bias them to activate and use phonological codes more than in silent reading. Second, it is entirely unclear whether the subjects are actually activating any meaning information when performing the naming task or simply recoding for pronunciation (M. Coltheart, Davelaar, Jonasson, & Besner, 1977). Since the goal is to understand the normal reading process, a task where the reader's goals are the same as in normal reading (i.e., comprehension) would be ideal. Last, the naming task not only requires the subjects to identify the word but also to plan and execute the motor response, resulting in reaction times that are not very sensitive to the time course of lexical access or any phonological influences thereon. Apparent effects of phonological codes may in fact have come online postlexically rather than prelexically.

Semantic categorization and semantic relation tasks. In an attempt to ensure that subjects are identifying the meaning of target words and to avoid biasing the generation of phonological codes, other researchers have made use of semantic categorization or semantic relations tasks. In this task, subjects are required to determine whether a target is part of a given category (or whether two words are semantically related); the rationale is that they must be identifying the word and accessing its meaning in order to perform well. Using a semantic relation task, Lesch and Pollatsek (1998) observed that subjects made more errors and took longer to respond "no" to homophones (BEECH after SAND) and pseudohomophones (BEAD after PILLOW) of semantically related words (*beach* and *bed*).[1] They took this as evidence that initially all potential phonological representations of a given letter string are assembled during lexical access. Similarly, in a series of categorization tasks, Van Orden and colleagues found increased rates of false positive errors during semantic categorization tasks to both homophones (Van Orden, 1987) and pseudohomophones (Van Orden, Johnston, & Hale, 1988) of category members, suggesting that assembled phonology was activating the lexical representation of the category member (e.g., reading ROWS or ROZE and activating the lexical entry *rose* through assembled phonological codes). Interestingly, there is evidence that when orthographic overlap between the homophonic foil and the actual category member is low (e.g., *slay* to *sleigh*), the homophone effect is small (Van Orden, 1987) or even nonsignificant (V. Coltheart, Patterson, & Leahy, 1994; Jared & Seidenberg, 1991). This calls into question whether the effect is truly phonological in nature or whether it is actually being driven by orthography. Indeed, Grainger, Kiyonaga, and Holcomb (2006) recorded event related potentials (ERPs) while subjects monitored visually presented target words for animal names. They included backward masked primes that were either homophones of a category member, transposed letter neighbors of a category member, or unrelated. They found evidence for phonological and orthographic priming on the same component (the N250) but observed that the orthographic priming effect emerged slightly earlier (~25 ms). However, Van Orden (1987) employed a backward masking paradigm as well and found that, at short SOAs, homophones with high and low orthographic overlap elicited equal rates of false positives, suggesting an earlier time course for phonological codes. Finally, there is some indication from semantic categorization tasks that assembled phonology is always used to get to the meaning of low frequency words but that the meanings of high frequency words are not necessarily phonologically activated (Jared & Seidenberg, 1991), thus providing some evidence for dual routes to meaning.

Besides the fact that the data are not as clear as in naming tasks, there are again a number of potential issues with drawing clear inferences about the use of phonological codes during normal reading from these semantic categorization tasks. First, as with the naming task, the semantic categorization task also suffers from

[1] Here, BEAD is considered a pseudohomophone or "false homophone" because it could be pronounced like *bed* through the generation of prelexical, assembled phonological codes (e.g., like its neighbor *head*). However, it is not actually a homophone of *bed* according to its lexical phonological code.

lack of sensitivity. Beyond requiring motor planning and a motor response, the categorization task also requires subjects to make a decision (taking subjects even longer to initiate a response than in the naming task). Especially in the case of longer "no" responses, it is unclear whether any apparent phonological influences truly result from prelexical, assembled phonology, or whether they could in fact arise later as a function of addressed phonology after lexical access has already been achieved, potentially further slowing the "no" responses (M. Coltheart et al., 1977; Van Orden, 1987). However, this task also produces false positive errors (e.g., responding "yes" to ROZE as a member of the category Flower), which does seem to suggest an early role for phonological coding. Indeed, M. Coltheart et al. (1977) proposed that finding evidence that phonological codes are used in making "yes" responses would serve as "unequivocal evidence" for the view that lexical access is mediated by phonology (p. 551). Furthermore, in these studies subjects see the category for some amount of time and then subsequently categorize target words. It is therefore possible that the category names may prime potential exemplars, especially since many of the categories were rather specific (e.g., *part of a horse's harness*; see Jared & Seidenberg, 1991). The task then might actually be more of a matching task where subjects activate a number of potential exemplars and compare target words against this list. Since the exemplars would likely be generated on a phonological basis (silent speech production), this might in turn influence the false positive rate to homophonic foils. In support of this explanation, Jared and Seidenberg (1991) directly compared semantic categorization task performance for broad and specific categories and found that error rates to homophonic foils were lower when broad categories were used, suggesting that some of the results may be due to priming. Finally, in some cases (e.g., Van Orden, 1987), subjects were asked to name the target word after making their categorization decision, subjecting those results to the criticisms of the naming task as well.

Lexical decision. Since the question of interest is whether phonological codes are used in lexical access, several studies have relied on the lexical decision task to assess this. The rationale is that subjects must have identified the word (at least to some extent) in order for them to respond "yes," indicating that a letter string is a word, though it is slightly less clear what they have done when they respond "no" to a nonword letter string. Additionally, the lexical decision task is simpler than the semantic categorization task. To examine the potential role of assembled phonology in lexical access, several studies have examined lexical decisions to pseudohomophones and have generally obtained the same results—more errors and longer lexical decision latencies for pseudohomophones than nonhomophonic nonwords (M. Coltheart et al., 1977; McCann & Besner, 1987; McCann, Besner, & Davelaar, 1988; Rubenstein, Lewis, & Rubenstein, 1971; Seidenberg, Petersen, MacDonald, & Plaut, 1996). Since subjects have difficulty responding "no" to pseudohomophones, it seems that they are activating the pseudohomophone's phonological code and that this assembled code is in turn activating the lexical representation of the real-word homograph. Since the lexical decision task does not in any way require subjects to activate phonology, it would be advantageous for subjects to rely on the supposedly faster direct route from orthography to meaning. The fact that they still activate phonological codes has been interpreted as evidence for the necessary use of phonological codes in lexical access.

Additionally, Drieghe and Brysbaert (2002) adopted their associative priming-while-naming manipulation to the lexical decision task to avoid the necessary activation of phonology inherent in the naming task. Believing lexical decision to be a more valid test, they used associate priming during the lexical decision task. Extending the results from naming, at a short SOA (57 ms) they observed priming of the same magnitude for associates, homophones of the associates, and pseudohomophones of the associate. At a long SOA (258 ms) priming from homophones was reduced, but priming from pseudohomophones was still observed. As a final test of the automaticity of phonological coding, they created a situation in which relying on phonological information would be detrimental to performance and explicitly instructed subjects that that was the case. To do this, they replaced all of the nonword targets with pseudohomophones and told subjects that they would be making lexical decisions to words and nonwords that sounded like words. In this variation, they tested only the short SOA and found priming for pseudohomophones of the associate but not homophones of the associate—a pattern of data consistent with the long SOA in the previous experiment. They interpreted these results, in accordance with the activation-verification model, as demonstrating that individuals may have some control over the rapidity with which they disambiguate between multiple activated lexical representations during the verification/cleanup stage but have no strategic control over the prelexical activation of phonology, which is automatic and not subject to strategic control (see also Jared & Seidenberg, 1991).

Grainger and Ferrand (1994) used phonological priming in a lexical decision task with a short SOA (57–64 ms) and found that higher frequency homophonic primes resulted in reduced lexical decision latencies for lower frequency targets (relative to unrelated primes), whereas higher frequency orthographically related, nonhomophonic primes actually increased lexical decision latencies for lower frequency targets. However, once pseudohomophones were introduced in the lexical decision task (as target foils), higher frequency phonologically related primes resulted in longer lexical decision latencies. They interpreted the results as evidence for the early assembly of phonological codes from the prime, concluding that when the target is a homophone, it is essentially a case of repetition priming, as the phonological information across prime and target is identical. The fact that the facilitation from homophonic primes changed to inhibition in the presence of pseudohomophone foils was interpreted as potential evidence that the use of assembled phonology may be under voluntary control, in that it can be suppressed. This runs counter to the conclusions of Drieghe and Brysbaert (2002).

Unfortunately, the lexical decision task is not immune to criticism either. One major concern is that in order to say "yes," a subject may not need to actually access the meaning of the word; rather, most of the time they could simply rely on the relative familiarity that they have with a given letter string to assess the likelihood that it is or is not a word (e.g., Balota & Chumbley, 1984). Even if this is the case, there is still something interesting to be said about that fact that pseudohomophones result in more errors than nonword orthographic controls. If the familiarity check were conducted on a strictly visual basis, we would not expect to find differences in the familiarity of pseudohomophones and nonword controls matched for orthographic overlap. The fact that pseudohomophones do result in more errors suggests that phonological codes are being used, even if complete lexical access is not underlying task performance.

Word identification. Whereas the previous methods measure reaction times for speeded responses, a final method, word identification, does not require a speeded response. Instead, subjects are instructed to identify a brief, visually presented target word and to write it down on a piece of paper or enter it on a keyboard. It is somewhat similar to naming, in that subjects do not have to make any decision, but because it does not require a verbal response, it does not necessitate the activation of phonological codes.

Using a four-field masking paradigm (presentation sequence: mask, prime, target, mask) with mean field durations between 35 and 40 ms, Humphreys, Evett, and Taylor (1982) found that subjects were better able to report the target word when a homophonic prime preceded the target than when the prime was a control word with the same amount of orthographic overlap as the homophonic prime. Additionally, the phonological priming effect was observed regardless of whether the target word was a regular word or an exception word. However, when they used pseudohomophones as primes, they found that there was no increase in priming over and above the orthographic control. They interpreted their results as supporting the automatic access to phonology via the direct lexical route rather than assembled phonology.

Using priming and a backward masking paradigm, Perfetti and colleagues (Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988) expanded and clarified the results of Humphreys et al. (1982). By varying the degree of overlap between the target and subsequent letter mask, Perfetti and colleagues were able to measure the masking reduction of homophonic and orthographic masks compared to unrelated control masks. The logic behind this method is that visual masks ordinarily disrupt target processing and that any reduction in the effect of the mask will be due to overlapping "features" (here, abstract letter or sound information as opposed to strictly visual information, since the target and mask are presented in different cases) of the mask and target. Across both studies, Perfetti and colleagues (Perfetti & Bell, 1991; Perfetti et al., 1988) found that both orthographic and phonologically related pseudoword masks disrupted target identification significantly less than unrelated control masks across multiple target presentation durations. Furthermore, Perfetti et al. (1988) found that pseudohomophone masks presented for 16 or 25 ms produced significantly less disruption in the identification of the target word (presented for 30 or 33 ms) than orthographically related pseudoword masks. Likewise, Perfetti and Bell (1991) found that pseudohomophone masks presented for 30 ms produced significantly less disruption in the identification of target words (presented for 35, 45, or 55 ms) than orthographically related pseudoword masks. Additionally, in a direct follow-up to Humphreys et al. (1982), Perfetti and Bell (1991) presented pseudohomophone primes for 25, 35, 45, 55, or 65 ms followed by a target presented for 30 ms, then a pattern mask. They found that the phonemic effect emerged slightly later than the orthographic effect and was in fact only reliable beyond 35 ms (i.e., at prime durations of 45–65 ms). Since Humphreys et al. (1982) used prime presentation durations between roughly 35 and 40 ms, they may have only captured the emergence of phonological effects, and this may have contributed to their null effect of pseudohomophone priming. Critically, Perfetti and Bell concluded that priming and backward masking paradigms tell the same story—namely, that assembled phonological codes can be activated prelexically.

These word identification tasks have the advantage of avoiding overt decisions, but they still rely on offline measurements (here, percentage of targets correctly identified) and therefore may tell us little about the online processing in such tasks. For one, it is unclear whether subjects are actually accessing the meaning of the target words; it is certainly not necessary that they process the meaning in order to perform the task. Additionally, exactly what is happening during the masking procedure is not well understood, and it is difficult to conclude that the subject has no access to the target once the mask is presented, or that target processing ends at the exact moment that the target is replaced by the mask on the computer screen (see Rayner, Pollatsek, Ashby, & Clifton, 2012, for a review).

Conclusions from response time methods and nonreading tasks. The large body of work aimed at understanding the role of phonological coding during lexical access that has relied largely on single word reading tasks can only get us so far. Although it is certainly the case that many of these studies find evidence for the use of phonological codes while performing the different tasks, I have discussed how these varying tasks may or may not reflect the process of normal lexical access during reading. Although these studies provide evidence that the language processing system can use phonological codes, it is unclear, for a number of reasons, whether any of them can really assess the use of phonological codes during normal reading.

First, it is highly unlikely that any of these tasks accurately capture the normal reading process. For one, the goal in normal reading is comprehension, whereas the goals in these studies vary considerably and may not always be obvious. In semantic categorization the goal is seemingly to identify the meaning of a given word in order to report if it is a member of a given category, but as previously discussed, in actuality the goal might be to generate expectations about potential candidate words and then to perform a matching task when the target word is presented. In lexical decision, the goal is seemingly to attempt to access the orthographic string in one's lexicon in order to say whether the letter string is a word. In practice, however, the task may be performed with relatively high accuracy by simply performing a series of familiarity or frequency judgments and categorizing letter strings as words or not on the basis of one's subjective familiarity. Even if subjects are indeed accessing letter strings in their lexicon in order to say "yes" to words, it is entirely unclear what subjects are doing in order to allow them to decide "no" for a nonword string. In naming, the goal is to produce the word aloud, and it is entirely unclear whether there is any need to access the word's meaning in order to be able to do this. In word identification, subjects need only recreate the orthographic information that was presented to them, and it is again unclear what strategies they employ, though meaning access is clearly not essential. It seems that at best we can say that to the extent that any of these tasks actually reflects the process of lexical access during normal reading, then phonological codes can influence lexical access under some conditions. However, looking only at the evidence from single-word studies, we cannot say with certainty that this influence extends to the reading of sentences and texts with the goal of comprehension.

Evidence From Reading

Since the extent to which phonological codes are used during online reading for comprehension is of primary interest, it seems only appropriate to study the use of phonological codes during reading tasks. To this end, several lines of research using mainly eye-tracking and neurophysiological recording (EEG and MEG) but also sentence acceptability judgments and proofreading tasks have attempted to answer this question with more ecologically valid and sensitive tasks.

Fast priming during reading. As previously discussed, evidence from priming in single word reading tasks has converged on homophone priming effects emerging at prime durations between 30 and 60 ms (Drieghe & Brysbaert, 2002; Humphreys et al., 1982; Lesch & Pollatsek, 1993; Lukatela et al., 1993; Lukatela & Turvey, 1994a, 1994b) and generally find that pseudohomophone priming effects emerge around the same time (i.e., by 60 ms, Drieghe & Brysbaert, 2002; Ferrand & Grainger, 1992; Lukatela & Turvey, 1994b; Perfetti & Bell, 1991; but see Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003) but that they endure at longer durations when homophone priming effects disappear (Drieghe & Brysbaert, 2002; Lukatela & Turvey, 1994a).

Several lines of research have used the fast priming paradigm in reading studies (Sereno & Rayner, 1992) to assess the time course of early phonological coding during reading. In this paradigm, an invisible boundary (Rayner, 1975) is placed before a target word; while a subject is reading the sentence, a random letter string is displayed in place of the target word. Once a reader's eyes cross the invisible boundary, the letter string is replaced with a prime for a short duration; then, in turn, the prime is replaced with the target word for the remainder of the trial. Target reading times, usually gaze duration (the sum of all fixation durations on a target word before moving off of it), are recorded for the target word after a related prime and compared to the unrelated prime condition to determine what information the reader can begin to extract from the prime within a given duration.

In support of the early time course found in other priming tasks, Rayner, Sereno, Lesch, and Pollatsek (1995) found a significant reduction in gaze durations on targets after both homophone and pseudohomophone primes, at prime durations as short as 36 ms. That is, subjects spent significantly less time reading the target word following a phonologically related prime compared with target reading time after an orthographically similar prime. Although it may be tempting to conclude that phonological information is being extracted by as early as 36 ms, the fast-priming paradigm cannot actually reveal the earliest time course of phonological influences. Rather, the only inference that can be made is that subjects have encoded enough information within 36 ms to allow phonological coding to begin. Indeed, Rayner et al. (1995) conceded that the exact time course of phonological coding could not be precisely determined. Given that gaze durations to the target words in their data averaged 350 ms and that the last 100–150 ms of the gaze duration are devoted to programming the subsequent eye movement (Rayner, Slowiaczek, Clifton, & Bertera, 1983), they conservatively concluded that phonological codes are influencing lexical access within the first 200–250 ms of processing.

Because Rayner et al. (1995) only found significant effects of priming at their longest tested prime duration (36 ms), their results do not speak to the upper bound of phonological priming effects. In order to better test the time course of phonological extraction, H.-W. Lee, Rayner, and Pollatsek (1999) used the fast priming paradigm with prime durations of 29, 32, 35, 38, and 41 ms. They found significant homophone priming effects at all prime durations between 29 and 35 ms. Additionally, they found significant orthographic priming at all durations and significant semantic priming only at the 32-ms prime duration. Their results point to a time course where orthographic codes come online first and slightly earlier than phonological codes. Critically, phonological codes exerted an influence that was at least as early as semantic codes, if not earlier—suggesting that either phonological codes and semantic codes are being accessed in parallel or that phonological codes are necessary for semantic activation. These data, however, do not answer the question of whether the phonological codes are being assembled prior to lexical access (prelexical) or if orthographic codes are being used to retrieve the addressed phonological codes from the lexicon (lexical).

To explore the lexical or prelexical time course of phonological coding, Y.-A. Lee, Binder, Kim, Pollatsek, and Rayner (1999) also used a fast priming paradigm with both homophone and pseudohomophone primes (as well as an orthographic control word and pseudoword primes). They used prime durations of 32, 35, 38, and 42 ms and found significant orthographic priming at all prime durations, phonological priming from homophones at 32 and 35 ms, and no priming from pseudohomophones at any prime duration tested. Additionally, Y.-A. Lee et al. only observed priming from homophones when the prime was high frequency (the frequency of the target did not matter). The modulation of priming effects as a result of frequency suggests that a rapid extraction of phonological codes is crucial in order to obtain phonological priming and that the extraction of these early phonological codes from orthographic information is lexical in nature. This study does not necessarily rule out the possibility that phonological codes can also be assembled early and used in lexical access, but it does suggest that these assembled codes may come online slightly later. The fact that homophone priming is not observed at the longer durations is taken as evidence that conscious awareness of the prime interferes with phonological priming (through inhibition of competing lexical entries), and the same story may be true for pseudohomophones in this task. That is, by the time assembled phonological codes from the pseudohomophones (and also the low frequency homophones) become available to aid lexical access, the reader is also consciously aware of the prime, thus canceling out any potential priming effects.

H.-W. Lee, Kambe, Pollatsek, and Rayner (2005) again used the fast priming paradigm to directly test whether there is any evidence of pseudohomophone priming at longer durations. They tested pseudohomophone and orthographically related primes at durations of 32, 44, and 56 ms. At the two shorter durations, they replicated the results of Y.-A. Lee et al. (1999) that no pseudohomophone priming effects were observed. Additionally, they found no evidence for pseudohomophone priming effects at the longer, 56-ms prime duration. In a second experiment, they also found no priming from pseudohomophones presented for the same duration during a naming task. Since conscious perception of the prime does not interfere with priming effects during naming (pseudohomophone priming effects were observed at a 200-ms prime duration), the lack of phonological priming at a 56-ms duration in both tasks suggests that the phonological codes could not yet be assembled to influence lexical access—providing additional evidence for a delay in the activation of assembled, prelexical phonological codes.

The fast priming paradigm offers several advantages over the response time and single-word identification tasks. First, subjects are engaged in a reading task with the goal of comprehending the meaning of the sentences they read. Second, they are not required to make any overt response or decision, so there is no additional processing required. Third, because they are not making any additional response, processing time is simply measured as the amount of time they spend fixating the target word, which results in much shorter reaction times (RTs) than in the response time tasks and therefore a much more sensitive measure of lexical processing. Despite these advantages over the nonreading tasks, there are still two issues with the fast priming studies that make generalizing to normal reading slightly problematic. First, the nature of the fast priming task means that while subjects are reading a word, the visual information is changed while they are fixating it—something that clearly does not happen during normal reading. Second, before a subject fixates the target word, that word is replaced with a random letter string, thus denying the reader any accurate parafoveal information about the upcoming word. Since subjects can begin processing a word while it is in the parafovea (i.e., before it is actually fixated with central, foveal vision), denying subjects accurate parafoveal information can disrupt the normal reading process (for a review, see Schotter, Angele, & Rayner, 2012).

Parafoveal preview benefit studies. One way to get around the issue of having the display change while a subject is fixating on it is to only change information while a subject is making a saccade and vision is effectively suppressed (see Matin, 1974; Campbell & Wurtz, 1978). Studies that manipulate text during a saccade typically employ a boundary paradigm (Rayner, 1975) to manipulate the upcoming parafoveal information that is available to readers prior to fixation. An invisible boundary is inserted before a target word, and a display change is executed when a reader makes a saccade across the boundary. Instead of manipulating the information that subjects first see when they land on a target word, this method can be used to manipulate the type of parafoveal information about the target word that is available (i.e., the preview). In this way, researchers can manipulate the informational overlap of a preview word (the word in the parafovea before the eyes cross the invisible boundary) and the target word that is eventually fixated and measure the resulting preview benefit. By the time the subject is fixating on the target word (if everything has gone correctly), the display change will have already been executed, and subjects are largely unaware of the manipulation (Slattery, Angele, & Rayner, 2011).

Beyond phonological codes being activated early on in processing, some research using the boundary paradigm has provided evidence that phonological coding can even begin on a word before it is actually fixated and that the information in these early phonological codes can be used to integrate information across saccades (see Rayner, 1998, 2009 for reviews). One clear demonstration that phonological coding begins on a word prior to a fixation on the word is the presence of a phonological preview benefit—reduced processing time following a phonologically related preview than an unrelated letter string.

Using this boundary paradigm in some silent reading (and naming) studies, several lines of research have demonstrated evidence for a phonological preview benefit. Pollatsek, Lesch, Morris, and Rayner (1992) observed shorter processing time on a target word following a homophonic preview than a nonhomophonic preview matched in orthographic overlap. Miellet and Sparrow (2004) found no significant difference between pseudohomophone previews and identical previews, suggesting that phonological codes can be assembled prior to fixation and used in lexical access (see also Lesch & Pollatsek, 1998, for additional evidence that assembled phonological codes can be obtained prior to fixation).

Henderson, Dixon, Petersen, Twilley, and Ferreira (1995) found that words with phonologically regular initial trigrams benefitted more from an identical preview and were more likely to be correctly identified from a preview alone than those with phonologically irregular initial trigrams. Additionally, the early use of phonological codes is not restricted to alphabetic languages, as phonological preview benefit has also been observed in Chinese, a character-based language (Liu, Inhoff, Ye, & Wu, 2002; Pollatsek, Tan, & Rayner, 2000; Tsai, Lee, Tzeng, Hung, & Yen, 2004).

Although there is substantial evidence to suggest that subjects are able to activate phonological information that they obtain parafoveally to influence processing on the word once they actually fixate on it, the exact nature of this preview benefit is unclear. One possibility is that the orthographic information is simply recoded as phonological information in order to integrate information across saccades while reading. Indeed, studies using the boundary paradigm to investigate the integration of preview and target information have quite convincingly demonstrated that purely visual information is not integrated across saccades. Rayner, McConkie, and Zola (1980) found that changing the case of a word between preview and target (e.g., *CHEST* presented as a preview for *chest*) had no effect on naming speed; they still observed a preview benefit. Additionally, McConkie and Zola (1979) had subjects read sentences composed of alternating text that changed with each subsequent fixation (e.g., *MaNgRoVe* to *mAnGrOvE*) and found that readers were unaware of the manipulation and that it did not have any additional effect on their reading performance (above the effect of reading alternating text; see Slattery et al., 2011, for a recent replication of this finding).

These studies do not necessarily implicate phonological codes in integrating information across saccades; rather, it could be that some abstract letter code is being extracted and used to integrate information across saccades. However, the fact that there is an advantage of homophonic previews even when orthographic overlap is low (e.g., *chute*, *shoot*) suggests phonological involvement (Pollatsek et al., 1992). Additionally, there is evidence to suggest that syllable information is encoded parafoveally and integrated across saccades, such that readers spend less time fixating a word following a preview that maintained valid initial syllable information (Ashby & Rayner, 2004; see also Carreiras, Alvarez, & de Vega, 1993; Carreiras & Perea, 2002; J. Y. Chen, Lin, & Ferrand, 2003; Ferrand, Segui, & Grainger, 1996; Hutzler, Conrad, & Jacobs, 2005; Perea & Carreiras, 1998, for demonstrations of syllable effects on visual word recognition in Spanish, German, French and Chinese; and Ashby & Martin, 2008, for evidence from lexical decision with parafoveal previews) and are more likely to skip a one-syllable, five-character word than a two-syllable, five-character word (Fitzsimmons & Drieghe, 2011). Readers also spend less time fixating a word following a preview whose vowel letters encode the same vowel phoneme as the target word (e.g., less time reading *chirp* following *cherg* than *chorg*), suggesting that readers begin encoding vowel phonemes parafoveally, even when the orthographic information between preview and target conflicts (e.g., *cherg–chirp*), again implicating phonological codes in the integration of information across saccades (Ashby, Treiman, Kessler, & Rayner, 2006). If it is the case, as the previous data suggest, that phonological codes are used to integrate information across saccades, they may in fact also serve as an early source of constraint during lexical access, limiting potential lexical candidates (e.g., Folk & Morris, 1995) or partially activating the correct candidate (Lima & Inhoff, 1985).

Finally, there is some evidence that less skilled readers do not use phonological codes effectively. Chace, Rayner, and Well (2005) demonstrated a lack of phonological preview benefit for less skilled readers during reading. Although it is unclear whether the inability to use phonological preview information is contributing to the lower skill level of these readers or if their lower skill level is rendering the use of phonological preview information useless, the correlation of reading success with the effective use of phonological codes does further implicate this skill in the normal reading process.

Taken together, these data suggest that readers are activating phonological codes during reading. Furthermore, the fact that there is evidence for phonological processing before a word has been fixated suggests that the codes can begin to be assembled prelexically. It is unclear whether this initial coding is what ultimately drives lexical access, but there is no reason to assume that this code cannot aid lexical access; and in fact, if it is already partially activated, the most parsimonious conclusion is that it can. This, however, does not mean that these codes necessarily aid lexical access (though the Chace et al., 2005, data suggest that normal reading may be disrupted without proper use of phonological codes). In line with the dual-route model, it could be that upon fixating the word, its orthography allows for more rapid direct lexical access. The preview studies cannot speak to the use of phonological codes once a word is actually fixated; for that, I turn to other reading studies.

Reading of phrases, sentences, and discourse. The next category of reading studies is one in which the text is not manipulated during reading. Here, subjects are asked to read short phrases, sentences, or longer bodies of text while having their eye movements recorded, performing sentence acceptability judgments, proofreading, or some combination of the previous tasks. Typically homophones or pseudohomophones are embedded in the text, and processing of these words is assessed to determine whether phonological codes are being used to access the meaning of words. Alternatively, some studies have subjects silently read visual tongue-twister sentences (sentences that repeat initial consonants) to determine if and at what point processing of such sentences is disrupted due to the activation of phonological codes.

McCutchen and Perfetti (1982) recorded reaction times as subjects performed sentence acceptability judgments to visual tongue-twister sentences and matched phonetically “neutral” sentences. They found that subjects took longer to classify tongue-twister sentences as acceptable relative to control sentences, suggesting that subjects were automatically activating phonetic representations while silently reading, a result that was replicated in a later study by McCutchen, Bell, France, and Perfetti (1991). Furthermore, McCutchen et al. (1991) also had subjects hold to-be-recalled five-digit sequences in memory while reading each sentence. They varied whether each tongue-twister sentence was paired with a digit sequence that repeated the same word-initial phoneme or a different phoneme and found interference in the digit recall task when initial phonemes were shared across the digits and tongue twisters, again suggesting that subjects were activating phonological codes while silently reading. To determine whether these codes were being generated prelexically or postlexically to aid comprehension, McCutchen et al. (1991) ran a second experiment in which subjects performed modified lexical decisions to lists of tongue twisters (i.e., decide whether a nonword was present in the list). Subjects did not take longer to perform lexical decisions to tongue twisters than to control sentences, suggesting that the phonological activation that they observed in the earlier experiment likely came online to aid comprehension and did not mediate lexical access (though this does not necessarily mean that it was generated postlexically).

Other early work examining phonological coding during reading had subjects read short phrases and decide whether they made sense (Baron, 1973; V. Coltheart, Avons, & Trollope, 1990; V. Coltheart, Laxon, Rickard, & Elton, 1988; Doctor & Coltheart, 1980; Johnston, Rugg, & Scott, 1987; Treiman, Freyd, & Baron, 1983). Critically, words in the phrases were sometimes replaced with homophones and/or pseudohomophones that rendered the phrases orthographically unacceptable, but phonologically acceptable (e.g., SHE HAS BLOND HARE). Across these studies, false positive rates were higher to sentences containing homophones or pseudohomophones than to sentences containing nonhomophonic controls (e.g., SHE HAS BLOND HARM), suggesting that subjects were activating phonological codes. Furthermore, greater incidence of false positives occurred to sentences containing both pseudohomophones and irregular homophones, indicating the early use of both assembled and addressed phonological codes.

Because of concerns over the simplicity of the phrases used in the previous studies, Daneman and Stainton (1991) had subjects perform a proofreading task while reading longer passages of connected text that included homophone errors. They found that subjects were less likely to notice homophone errors but that they were faster to repair the error (i.e., supply the correct word) when the error was homophonic in nature. They interpreted these findings as evidence that assembled phonological codes are used in lexical access. Reading a homograph activates the phonological code for that homograph, which results in all words with that phonology being accessed in the lexicon, thus leading to more errors during proofreading (failing to detect an incorrect homophone) but easier repair when the error is detected, as the correct homophone has already been accessed from the lexicon. However, as the goals of proofreading are different than normal reading for comprehension, it is unclear whether the results would be the same without an overt task.

Daneman and Reingold (1993) had subjects read passages with homophonic and orthographic errors while their eye movements were recorded. Subjects were told to simply read the texts for comprehension and were not alerted to the presence of errors. Eye movements revealed that early processing (gaze duration) was slowed for both homophonic and orthographic errors but that later measures (total time, repair time) were significantly shorter for homophonic errors. This suggests, contrary to the proofreading results, that readers are equally sensitive to both homophonic and orthographic errors and consequently that phonological codes may not be driving lexical access.

In an attempt to reconcile the proofreading and eye movement results, Daneman, Reingold, and Davidson (1995) combined the two tasks and added a frequency manipulation. Regardless of the relative frequencies of the correct word and its homophonic error, Daneman et al. replicated the previous results of Daneman and Reingold (1993), namely, that initial processing on homophonic errors and orthographic errors did not differ, but that later measures revealed an advantage for the homophonic errors. Furthermore, they replicated the proofreading results of Daneman and Stainton (1991) that subjects were less likely to report noticing homophonic errors than orthographic errors. Interestingly, even though homophonic errors were less likely to be overtly recognized (or at least reported), the eye movement data revealed that homophonic errors were equally as disruptive in early eye movement measures as orthographic errors. These results again support a delayed role for phonological coding during lexical access (even for lower frequency words) and additionally caution against drawing inferences from the results of reading studies with secondary overt tasks (like proofreading).

However, in a follow-up to the studies of Daneman and colleagues (Daneman & Reingold, 1993; Daneman et al., 1995; Daneman & Stainton, 1991), Rayner, Pollatsek, and Binder (1998) recorded readers' eye movements while they read passages with homophone errors and orthographic errors embedded. Additionally, they varied the degree of target predictability and the orthographic overlap between homophone pairs. They obtained the same results as Daneman and colleagues when they collapsed across all levels of homophone pair orthographic overlap and only examined relatively later measures (gaze duration and total time). However, when they examined predictable targets with high degrees of orthographic overlap, they found that very early measures (first fixation duration and single fixation duration) did not significantly differ between correct and incorrect homophones. Additionally, given a highly constraining context and high degree of orthographic similarity, subjects never detected the homophone errors on a large percentage of trials (~40%–73% of trials across different experiments). They argued that the lack of an effect on the earliest eye movement measures was evidence for the early activation of phonological codes, and the fact that differences didn't begin to emerge until gaze duration and total time suggested that the orthographic discrepancy wasn't noticed until further downstream, potentially in line with the activation-verification model. Inhoff and Topolski (1994) found similar results for pseudohomophone errors embedded in passages, concluding that assembled phonological codes can also come online early to influence lexical access.

In a final attempt to reconcile the results of Daneman and colleagues (Daneman & Reingold, 1993; Daneman et al., 1995; Daneman & Stainton, 1991) with those of Rayner et al. (1998) and Inhoff and Topolski (1994), Jared, Levy, and Rayner (1999) examined the processing of single sentences and stories containing homophone and pseudohomophone errors. Across a series of studies, they had subjects perform proofreading tasks and read silently while their eye movements were recorded. Critically, they varied the frequency of the target homophone and the incorrect homophone and found evidence for phonological coding, measured as a failure to detect homophone errors while proofreading and no difference between early eye movement measures (gaze duration) to homophone foils and correct homophones, but only for low-frequency homophone errors that replaced low-frequency target homophones. They noted that Rayner et al. (1998) included more low-frequency homophone pairs than Daneman and colleagues (Daneman & Reingold, 1993; Daneman et al., 1995; Daneman & Stainton, 1991) and argued that this may have been the basis for their discrepant results (i.e., Rayner et al., 1998 found no difference in the early processing of correct homophones and homophone errors, whereas Daneman et al., 1995 did). Additionally, Jared et al. (1999) examined the performance of good and poor readers separately and found that good reader had significantly shorter gaze durations on correct target homophones than incorrect homophone errors (which did not differ from spelling controls), whereas poor readers had similar gaze durations on correct target homophones and incorrect homophone errors (which were significantly shorter than spelling controls). Taken together with the fact that poor readers also exhibited similar gaze durations to correct homophones and pseudohomophone errors, Jared et al. (1999) interpreted their results as demonstrating that poor readers activate phonological codes early, whereas good readers rely more on a direct route from orthography to meaning, except in the case of low-frequency errors where they too show evidence of phonological coding (e.g., Doctor & Coltheart, 1980).

As a final demonstration of the early use of phonological codes affecting eye movements during normal reading, Slattery, Pollatsek, and Rayner (2006) had subjects read sentences containing acronyms (e.g., FBI, CIA) while their eye movements were recorded. They varied whether the article preceding the acronym corresponded to the orthography or the phonology of the first letter of the acronym (e.g., *F* is a consonant, but its pronunciation begins with a vowel sound, "eff"). The hypothesis was that if early coding was strictly orthographic, then *a FBI agent* should not cause disruption; but if phonological codes come online early, then readers should demonstrate processing difficulty reading *a FBI* relative to *an FBI*. Indeed, the data revealed effects of phonological consistency as early as first fixation duration, again supporting an early role for phonological coding during normal reading.

Although eye-tracking during the silent reading of sentences and discourse provides a sensitive, online measure of cognitive processing, fixation durations include not only the time it takes for lexical processing but also the time it takes to program and execute an eye movement (a minimum of 100–150 ms). Therefore, for an average fixation of 250 ms, lexical variables that affect when the eyes move (and therefore the duration of a given fixation) must actually be exerting their influences within the first 100–150 ms, even though these effects aren't observed behaviorally until the eyes move (Sereno & Rayner, 2000; but see, e.g., Reingold, Reichle, Glaholt, & Sheridan, 2012; Sheridan & Reingold, 2012, for demonstrations using distributional analyses of eye movement data to examine the earliest influences of perceptual, lexical, or contextual variables on the eye movement record).

Neurophysiological recording while reading. Neurophysiological methods can be used to record millisecond-by-millisecond changes in the electrical potential (electroencephalography—EEG) or magnetic field (magnetoencephalography—MEG) of the brain, related to on-going cognitive (and perceptual) processing. As such, both EEG and MEG, like eye movements, provide sensitive, online measures of cognitive processing. Therefore, it is informative to examine the EEG and MEG record for evidence that might converge with the eye movement data in support of an early time course for phonological coding.

Several studies have recorded EEG or MEG data while subjects read single words and occasionally sentences with phonological manipulations. Using a priming paradigm, Ashby (2010) measured event-related potentials (ERPs—stimulus-locked averages of the EEG signal across many trials) while subjects silently read individual words with either two or three phonemes in their initial syllable (e.g., *pony* [po] or *ponder* [pon]). Primes were partial words that were either congruent (PO## or PON###) or incongruent (PON# or PO####) with the first syllable of the target word. Targets in congruent conditions elicited reduced N1 responses compared to incongruent conditions as early as 100 ms after target onset (see also Ashby & Martin, 2008), suggesting that syllable information is being encoded within 100 ms of reading a word.

In another priming study, Ashby, Sanders, and Kingston (2009) measured the time course of subphonemic processing during the silent reading of individual words. They measured ERPs to target words (e.g., *fat* and *fad*) that were preceded by nonword primes that were either congruent (FAK-fat) or incongruent (FAZ-fat) in terms of the subphonemic features (e.g., voicing) of the last consonant. Ashby et al. found that phonological congruency effects emerged around 80 ms, reducing the magnitude of the first peak of the N1 waveform, suggesting that subphonemic processing can begin within 80 ms of reading a word.

Recording MEG data, Cornelissen et al. (2009) had subjects passively reading words and consonant strings, and viewing faces. They found patterns of early inferior frontal gyrus activation (peaking between 125 and 130 ms) in response to words, which they interpreted as representing grapheme-to-phoneme conversion and the assembly of phonological codes (see also Pammer et al., 2004). These results were further supported by Wheat, Cornelissen, Frost, and Hansen (2010), who compared the MEG activity of subjects reading individual words (e.g., *brain*) preceded by pseudohomophone primes (BREIN), orthographic control primes (BROIN), or unrelated primes (LOPUS). In accordance with the results of Cornelissen et al. (2009), they observed stronger responses following pseudohomophone primes relative to orthographic primes, which emerged within 100 ms of target onset in the region of the inferior frontal gyrus and precentral gyrus.

Although the majority of studies recording EEG or MEG to investigate the time course of phonological processing have used single word stimuli, a few studies have used single-sentence stimuli and measured ERPs to sentence final words. Newman and Connolly (2004) compared the silent reading of single-sentences with sentence final words that were congruent ("The gambler had a streak of bad *luck*"), pseudohomophones of congruent words ("The ship disappeared into the thick *phog*"), incongruent words ("The dog chased the cat up the *queen*"), and incongruent nonwords ("The gas station is about 2 miles down the *bole*"). They observed an N270 response (thought to reflect conflict processing; e.g., Wang, Kong, Tang, Zhuang, & Li, 2000; Wang, Wang, Cui, Tian, & Zhang, 2002) to incongruent words and nonwords as well as pseudohomophones; however, although they also observed an N400 response (thought to index semantic incongruence or anomaly; e.g., Kutas & Federmeier, 2011; Kutas & Hillyard, 1980) to the incongruent words and nonwords, the N400 amplitude was reduced to pseudohomophones. Together, these results suggest that although the orthographic inappropriateness of the pseudohomophone was registered, the use of assembled, prelexical phonology for meaning access or semantic integration resulted in the attenuation of the N400 response.

However, in a similar study, Niznikiewicz and Squires (1996) failed to find attenuation of the N400 for homophones of sentence-final congruent words. They compared the silent reading of congruent target words (e.g., *plane*), homophones (*plain*), orthographic controls (*place*), semantic controls (*jet*), and unrelated words (*host*). They did find an increase in the N200 amplitude to homophones (relative to the control conditions), suggesting that phonological processing during sentence reading was taking place by at least 293 ms (the peak response), and likely earlier. However, contrary to the findings of Newman and Connolly (2004), they did not observe modulation of the N400 amplitude following the homophone relative to the orthographic or unrelated controls (see also, Ziegler, Benraïss, & Besson, 1999).

The neurophysiological studies point to a very early time course (on the order of 80–125 ms) for observable phonological influences during single word reading. Furthermore, the effects reported by Ashby (2010) and Ashby et al. (2009) highlight the richness of this early code, which includes both subphonemic and suprasegmental information (Halderman, Ashby, & Perfetti, 2012), and the results reported by Wheat et al. (2010) and Cornelissen et al. (2009) demonstrate that this early code can be assembled, as there is evidence for grapheme-to-phoneme conversion and the differential processing of pseudohomophones and orthographic controls. Because the results of the sentence reading studies focus on later components (e.g., N200 and N400), it is harder to draw conclusions about the time course of phonological influences. Although the results regarding the N400 response to phonologically related words are mixed, Newman and Connolly's (2004) finding that the N400 response to pseudohomophones was attenuated relative to incongruent controls does coincide with previously reviewed studies that reported that homophonic errors were less likely to be noticed than orthographic control errors during silent reading (e.g., Inhoff & Topolski, 1994; Rayner et al., 1998).

Conclusions From Reading Tasks

The evidence from fast priming, parafoveal preview benefit, and reading all converge in support of an early role for phonological codes that precedes lexical access. Fast priming provides some evidence that assembled phonological codes may come online slightly slower than addressed phonological codes (H.-W. Lee et al., 2005; Y.-A. Lee et al., 1999), but both homophones and pseudohomophones result in significant preview benefit, providing evidence that readers can begin to generate phonological codes (whether assembled or addressed) prior to actually fixating on a word (e.g., Miellet & Sparrow, 2004; Pollatsek et al., 1992). Data from normal reading studies reveal that readers are less likely to notice (at least initially) or be disrupted by homophonic errors embedded in texts than by orthographic control errors (e.g., Inhoff & Topolski, 1994; Rayner et al., 1998; but see Jared et al., 1999 for evidence that this might only be the case for poor readers or good readers reading low-frequency words); in fact, there is some evidence that they show reduced N400 responses to homophonic errors relative to orthographic errors (Newman & Connolly, 2004, but see Niznikiewicz & Squires, 1996). Finally, results from eye tracking and neurophysiological recording converge in support of an early time course for phonological processing during silent reading, with differential processing emerging between 80 and 125 ms in the ERP and MEG record (Ashby, 2010; Ashby et al., 2009; Cornelissen et al. 2009; Wheat et al., 2010) and as early as the first fixation on a word (e.g., Slattery et al., 2006), demonstrating yet again that phonological coding precedes lexical access.

The Inner Voice: Postlexical Phonological Codes

Regardless of the precise role for phonological coding in the process of lexical access, previous research also supports a role for it further downstream, to bolster short-term memory and aid in comprehension. Proponents of this later role of phonological coding generally believe that the codes are used to integrate information across sentences and/or to sustain information in working memory, since it has been argued that sound-based codes are the most stable and retrievable short-term memory codes (Baddeley, 1979). Others have also suggested that it plays a role in restoring prosody and intonation to the memory trace (e.g., Bader, 1998; Breen & Clifton, 2011, 2013; Fodor, 2002; Hirotani, Frazier, & Rayner, 2006; Kentner, 2012; for a recent review see Clifton, in press) and therefore, it has been argued that at least some component must come online postlexically, since there is no way to know the appropriate stress or intonation without a cursory processing of the sentence at several levels (e.g., Daneman & Newson, 1992). However, there is evidence to suggest that prosodic information can influence first-pass reading of a word (e.g., Ashby & Clifton, 2005; Breen & Clifton, 2011, 2013), suggesting that at least some aspects of prosody are being assigned during lexical access. Inherent in this prelexical/postlexical distinction is the notion that these postlexical codes represent a more complete, speech-like phonological representation—the subjectively experienced inner voice (i.e., potentially representing full prosodic and intonational information), whereas the earlier, prelexical codes might be more abstract or impoverished (e.g., Eiter & Inhoff, 2008; Frost, 1998; Oppenheim & Dell, 2008). Indeed, there is evidence that the inner voice has aspects that are very speech-like—for example, reflecting the speaking rate of the person who authored the text (e.g., Alexander & Nygaard, 2008; Kosslyn & Matt, 1977) and representing characteristics of a character's voice when reading dialogue (e.g., Kurby, Magliano, & Rapp, 2009; Yao & Scheepers, 2011). But again, there is substantial evidence for relatively rich, prelexical codes as well, which represent syllable information (e.g., Ashby, 2010; Ashby & Martin, 2008; Carreiras, Vergara, & Barber, 2005), vowel information (e.g., Abramson & Goldinger, 1997; Lukatela, Eaton, Sabadini, & Turvey, 2004), subphonemic information (e.g., voicing; Ashby et al., 2009), and reflect readers' regional accents (Filik & Barber, 2011). Therefore, this distinction is not clear-cut; and adding to the confusion, there are also no generally agreed-upon names or terminology for differentiating the pre- and postlexical codes.

This dichotomy does not imply that theories of early phonological coding deny that phonological codes can be used for integrating information and storing information in short term memory. The division is between theories that posit phonological coding prior to lexical access and those that theorize that phonological codes are not used until after lexical access has been achieved. In general, the opinions in the latter category are of two varieties. The first is that phonological codes come online during or after lexical access and aid comprehension downstream but are not necessarily implicated in lexical access (i.e., they are simply activated in parallel with orthographic codes or come online automatically when the word is accessed, e.g., Daneman & Newson, 1992; Daneman & Reingold, 1993; Daneman et al., 1995; Kleiman, 1975; Slowiaczek & Clifton, 1980). The second is that there are two codes, one that is used to aid lexical access and a second code that is used postaccess to bolster short-term memory (e.g., Baddeley, Eldridge, & Lewis, 1981; Besner & Davelaar, 1982; Besner, Davies, & Daniels, 1981; Eiter & Inhoff, 2008; Perfetti et al. 1988). Interestingly, very similar experimental procedures and results have been used to argue for these two different opinions. The difference of interpretation lies in the assumed nature of the code and the implications these assumptions have for the results of a large body of research reliant on concurrent articulation.

The concurrent/coarticulation ("suppression") technique has been widely used to study the role of phonology in the reading process. In general, there are two different types of coarticulation tasks: shadowing, where subjects hear a string of random numbers and repeat them aloud, and articulatory suppression, where subjects repeat some rehearsed string of numbers (e.g., counting repeatedly from 1 to 10) or a word or sound (e.g., "the-the-the", "cola-cola-cola," "blah-blah-blah"). The basic assumptions underlying these lines of research are that the vocal apparatus (i.e., the articulators or musculature) is involved in the production of (at least some varieties of) phonological codes, which I refer to as *subvocalization*, and that the vocal apparatus can only be engaged in one task at a time. As such, concurrent articulation will interfere with the ability to generate phonological codes from written orthography. Therefore, if suppression interferes with a reading task, phonological coding is assumed to be necessary or at least a part of the task under investigation. If there is no interference as a result of concurrent articulation, then phonological processing is assumed to be not involved in or at least not necessary for the task (e.g., Baddeley, 1979). The difference of interpretation arises when researchers have failed to find an effect of coarticulation during lexical access, leading some to conclude that phonological coding is not involved in, or at least not necessary for, lexical access (those advocating for only the later role of phonological coding for comprehension), and others to conclude that the type of phonological code used during lexical access is not articulatory in nature and therefore immune to any effects of coarticulation (those arguing for two codes—one used in lexical access and another for comprehension).

Effects of Articulatory Suppression on the Reading of Words, Sentences, and Discourse

Kleiman (1975) reported a series of studies using a shadowing technique to explore the use of phonological codes during the reading of words and sentences. He presented subjects with pairs of words and had them judge visual similarity, rhyme, and whether the words were synonymous. He found that shadowing incurred a cost (increased reaction times) across all tasks, but that the cost was significantly larger for rhyme judgments. He interpreted the lack of a significant effect on synonym judgments as an indication that phonological codes were not necessary for lexical access. To evaluate whether the use of phonological codes differed during the reading of sentences, participants were given a target word and then asked to read a sentence and make a judgment about the relationship between the target word and words in the sentence. Judgments were graphemic (Is there a word in the sentence that is visually similar to the target?), phonemic (Is there a word in the sentence that rhymes with the target?), category membership (Does the sentence contain a member from the target category?), or semantic acceptability judgments (Is the sentence meaningful?). There was no target word in the last case. Kleiman observed significant effects of shadowing on the phonemic judgments as well as the semantic acceptability judgments. Taken together with the fact that he failed to find an effect of shadowing on synonym judgments to pairs of words, a task seemingly requiring meaning access but without a memory component, he argued that the significant effect of shadowing on semantic acceptability judgments implicated the role of phonological coding in bolstering short-term memory to aid in comprehension and concluded that "speech recoding occurs in the working memory stage" (Kleiman, 1975, p. 335).

Using articulatory suppression techniques rather than shadowing, Baddeley and Lewis (1981) also had subjects perform rhyme judgments for pairs of words, but unlike Kleiman (1975), Baddeley and Lewis failed to find an effect of suppression on RTs or error rates for rhyme judgments or for homophony judgments of nonwords (though there was a trend toward slower, less accurate performance under suppression conditions). In a similar study, Besner et al. (1981) used a rhyme judgment task with nonwords and irregular words. The rationale was that if suppression interfered with prelexical phonology, it should have a greater effect on rhyme judgments for nonwords (which have no addressed phonology and must rely on assembled phonology) than for irregular words (which rely on addressed phonology). They found no effect of suppression on RTs in the rhyme task for nonwords or irregular words, nor did they find an effect on RTs for homophony judgments to pseudohomophones (though there were increases in error rates across all tasks when the rate of suppression was more rapid). They argued that the lack of an effect of coarticulation on RTs across the different tasks indicated the existence of two phonological codes—a prelexical code, which is immune to suppression, and an articulatory code used to maintain information in short term memory, which is not.

All of the previous studies agree that phonological codes are used to bolster short-term memory (see also Besner & Davelaar, 1982) and aid in comprehension, and that these codes are disrupted by suppression, but they differ in their conclusion about the use of a prelexical phonological code. Because Kleiman (1975) found no evidence that phonological codes were used to make synonym judgments, he argued that phonological codes are not used for lexical access. Faced with a similar null effect of suppression on judgments requiring lexical access (and in many cases the use of prelexical assembled phonology), Baddeley and Lewis (1981) and Besner et al. (1981) concluded that the phonological code used for lexical access was immune to the effects of suppression. Indeed, the failure of Besner et al. (1981) to find differential effects of suppression on the rhyme judgments for irregular words (where assembled phonological codes are useless or detrimental) and nonwords (where assembled phonological codes are necessary) certainly calls into question the validity of using the suppression technique to determine when phonological coding is implicated in lexical access, a point that will be returned to at the end of this section.

Beyond exploring the interfering effects of suppression on tasks involving single words and short sentences, several lines of research have used the paradigm to examine the processing of longer sentences and connected discourse. Here, the focus is on determining the precise role that the inner voice plays in bolstering working memory and aiding comprehension. Baddeley et al. (1981) had subjects classify sentences as meaningful or not, either silently or while coarticulating. They found that suppression had no effect on RTs but that subjects were more likely to accept an anomalous sentence as meaningful in the suppression condition. Because suppression had no effect on the processing of nonanomalous sentences, Baddeley et al. concluded that the inner voice is not necessary for obtaining the general meaning of a sentence, but it is necessary for the accurate processing required to reject sentences containing anomalous words. It is unclear whether this requirement would exist during any normal reading situation, so it is likely that the inner voice is used for more than error detection. In a second experiment, Baddeley et al. had subjects search for permutated pairs of words in sentences either silently, while coarticulating, or while tapping. Again they found that suppression affected the accuracy of error detection but not the speed of responding, suggesting that the inner voice may be used to maintain precise information about word order. Critically they did not find an effect of the concurrent tapping task, suggesting that the locus of the interference was auditory or articulatory in nature, rather than just an artifact of performing the dual task. To further tease apart these different hypotheses, they ran a third experiment where subjects were again looking for permutated words, but this time while suppressing or while listening to an irrelevant speech stream. They found that suppression affected error rates but that the irrelevant speech did not, suggesting that the interference effect is articulatory in nature.

Across a series of studies, Levy (1975, 1977) had subjects read or listen to trios of sentences (either silently or while counting aloud) and then respond to a recognition test in which they had to indicate whether a target sentence was one of the three previously presented sentences or if it had a slight change. Changes were either lexical (a synonym substituted for a word in the sentence) or semantic (the subject and object were switched). Levy found that concurrent articulation affected comprehension for both types of sentences if the subject was reading, but not if the sentences were presented auditorily (1975, 1977). However, in a later study, Levy (1978) found that subjects could make paraphrase judgments without interference from suppression but that suppression did interfere with verbatim memory performance, suggesting that reading for meaning was possible without subvocalization but that subvocalization was used to maintain the verbatim visual information in verbal form.

Building on these results, Slowiaczek and Clifton (1980) presented subjects with longer, coherent discourse that they either read or listened to, with or without concurrent articulation (counting aloud or repeating "cola-cola-cola"). Consistent with the results of Levy (1975, 1977, 1978), they found a greater effect of concurrent articulation on reading than listening, and they found that concurrent articulation did not impair subjects' ability to make paraphrase judgments. However, they did find that concurrent articulation severely impaired subjects' ability to draw inferences or integrate ideas across sentences. They argued that it may be possible to understand individual concepts without subvocalization, but that subvocalization is necessary for combining concepts and integrating information across sentences. They attributed the role of subvocalization in comprehension to either the creation of a more durable memory trace or the reintroduction of prosodic features that actually change the memory representation rather than just making it more durable.

Although Slowiaczek and Clifton's (1980) materials did require subjects to integrate information across multiple sentences, their paragraphs were still rather simplistic. In an attempt to extend their results to a more naturalistic reading situation, Daneman and Newson (1992) had subjects read four prose passages (all book excerpts) either silently while performing a concurrent counting task or while performing a concurrent tapping task. Performance on both basic comprehension and integrative comprehension questions suffered when subjects had to concurrently articulate, but not when performing the tapping task, suggesting that subvocalization is important for both local and global comprehension processes.

Taken together these results suggest that later phonological codes (the inner voice) are implicated in reading; that they are used to bolster short-term memory, especially verbatim representations (Levy, 1978) or precise word order (Baddeley et al., 1981), to combine concepts and integrate meaning across sentences (Slowiaczek & Clifton, 1980), and to aid basic comprehension when reading normal discourse (Daneman & Newson, 1992). Results also suggest that the inner voice is somewhat articulatory in nature (i.e., that it is subvocalized) as it is disrupted by concurrent articulation. Additionally, results seem to indicate that if prelexical phonological codes are activated, they are not articulatory in nature, as articulatory suppression does not interfere with lexical access. However, these latter conclusions depend on the suppression task actually denying the inner voice, while not incurring any additional processing demands.

Evaluation of the Suppression Task

Unfortunately, there are several concerns with using the suppression task that make interpreting the results of the previous studies challenging. One issue with the suppression technique is that it requires additional cognitive resources; therefore, any slowdown in reading speed or difficulty in reading comprehension may simply be the result of additional cognitive demands rather than denial of the inner voice more specifically. Furthermore, even when RTs remained high, some studies reported increased error rates under suppression conditions (Baddeley et al., 1981; Besner et al., 1981), suggesting that even when subjects can perform the task reasonably fast, there is still difficulty brought on by the dual task.

Baddeley (1979) found that subjects' ability to classify sentences as true or false suffered when they had a concurrent cognitive load (remembering a sequence of six digits) but not when they had to concurrently articulate (repeated digits 1–6). Although not conclusive, this suggests that comprehension is sensitive to cognitive load but potentially not to suppression specifically, unless the suppression task is sufficiently difficult. Additionally, rate of suppression has been shown to effect interference, with only faster rates of coarticulation causing interference in some cases (Besner et al., 1981). Perhaps faster rates of suppression involve the articulators more and lead to interference, whereas slower rates allow phonological coding to continue. Alternatively it could be argued that coarticulating at a faster rate is a more demanding task and therefore leads to interference (see Waters et al., 1985). One issue is that most of the previous studies do not quantify the cognitive load imposed by the suppression procedure or reading task that they used, though many do compare the suppression task to different concurrent tasks (e.g., Baddeley et al., 1981; Daneman & Newson, 1992) or the effects of suppression across different reading conditions (e.g., Kleiman, 1975).

Waters et al. (1985) suggested that "if either the reading task or the concurrent articulation task is sufficiently difficult, then interference effects are observed" (p. 29). Rather than simply comparing performance under their suppression condition to performance under other concurrent tasks, Waters et al. used the secondary task paradigm (Kahneman, 1973) to quantify the amount of general processing capacity taken up by the different interference tasks that they used, allowing them to covary out the general processing demands of interference conditions. Doing so revealed that concurrent shadowing (even fast shadowing) did not affect reading rate when general processing demands were taken into account (unfortunately, they did not test the effects of repetitive coarticulation, e.g., "blah-blah-blah"). The concurrent tasks that did interfere with reading were those that required translation of the stimulus and thus meaning access (e.g., digit convert, where subjects shadowed digits and responded with letters—hear *1* respond "A," hear *2* respond "B," etc.). Waters et al. concluded that such concurrent tasks seemed to interfere with semantic processes during reading.

Unfortunately, there are a few limitations of the Waters et al. (1985) findings. First, they had subjects reading passages but only recorded global reading time. Although the inclusion of passages makes the reading task more realistic, it is unfortunate that they did not report more local effects or specific areas of difficulty. It is unclear what is leading to longer reading times under certain conditions. Longer reading times could, for example, stem from rereading of the passage, longer individual fixations throughout, or specific problems with low-frequency words that may rely more on phonological processing. Even if shadowing isn't significantly affecting global reading measures, it might be leading to differential online processing. Additionally, after reading a passage, the subject was tasked with reproducing the passage in a free-recall task and completing a cloze task. These upcoming verbatim memory tasks may have altered the normal reading goal of comprehension. Nonetheless, the results of Waters et al. are important in that they demonstrate that shadowing, which has been widely used to study phonological coding and the inner voice, may simply use up cognitive resources rather than actually limiting phonological coding. Therefore, any interference effects that are observed cannot be attributed to denial of phonological codes or the inner voice as a result of suppression.

What is really needed is a technique that would render the inner voice useless without incurring additional cognitive load. One potential avenue to explore is the use of transcranial magnetic stimulation (TMS) to temporarily interfere with auditory processing, or phonological processing more specifically. Indeed, this procedure has been used to examine the roles that different brain regions (e.g., Wernicke's and Broca's areas) play in phonological processing (e.g., Andoh et al., 2006; Devlin, Matthews, & Rushworth, 2003; Gough, Nobre, & Devlin, 2005; Nixon, Lazarova, Hodinott-Hill, Gough, & Passingham, 2004) and specifically to explore the contributions of different brain regions to phonological coding while reading words, nonwords, and texts aloud (Costanzo, Menghini, Caltagirone, Oliveri, & Vicari, 2012). TMS could be administered during silent reading without requiring readers to perform a secondary task. As such, this method could prove superior to suppression techniques, so long as it is able to effectively block phonological coding, as it could be used without incurring additional cognitive load. Additionally, it is possible that some suppression techniques (e.g., repetitive coarticulation) may be less cognitively taxing than others, and a systematic test of these different procedures will be necessary if this paradigm is to persist.

Unfortunately, the suppression technique is not only called into question because of the general processing demands that it puts on the system but also because it might not be effective at blocking phonological coding or the inner voice. If this is the case, then any failure to find an effect of suppression does not necessarily mean that the inner voice was not implicated in the task, rather it might simply be the case that the suppression technique didn't fully keep the subject from using their inner voice (see Rayner et al., 2012 for a review).

Part of the reason for this criticism is that it is certainly possible (at least under some conditions) for the inner voice to persist while the articulators are busy. It might be the case that the inner voice is still interfered with under these conditions, but it can persist at some level. That is to say, the inner voice is not strictly articulatory in nature. This does not mean that the articulators are not sometimes active during silent reading, as studies using electromyography (EMG) have revealed muscle activity in the vocal apparatus during silent reading (e.g., Edfeldt, 1960; Hardyck & Petrinovich, 1970), that seemed to increase with text difficulty (Faaborg-Anderson, Edfeldt, & Nykøbing, 1958). However, when supplied with feedback, subjects were able to eliminate subvocalization (engagement of the vocal musculature), and reading comprehension, at least for easy texts, was maintained (Hardyck & Petrinovich, 1970). These results suggest that readers can still comprehend easier texts without involving the vocal apparatus; furthermore, it is unclear whether comprehension of the difficult text suffered because subjects could not subvocalize or because they were using cognitive resources to actively inhibit subvocalization. It is worth noting that the subjects tested by Hardyck and Petrinovich (1970) were students in a remedial English class; this suggests that they might have had difficulties reading and comprehending texts to begin with, something that might have simply been compounded by the additional task demands. Additionally, there is substantial evidence to suggest that inner speech is faster than overt speech (e.g., Anderson, 1982), suggesting that it is not fully tied to the movement of the articulators.

In sum, although potentially coexisting often during normal silent reading, the inner voice that purportedly aids comprehension during normal reading seems to be dissociable from the subvocalization that engages the articulators; and although the two likely represent the same speech code under normal reading situations, it seems possible to involve the articulators in a different task while allowing the inner voice to persist. As such, rather than trying to infer the roles of phonological coding and the inner voice by observing what happens to reading when those processes are interfered with (or when attempts are made to interfere with those processes), an alternative method is to manipulate texts in order to observe phonological processing during normal, silent reading (e.g., visual tongue-twister effects, McCutchen et al., 1991; McCutchen & Perfetti, 1982).

Is the Inner Voice More Than an Epiphenomenon?

The fact that the exact role of the inner voice is not completely understood has led some researchers to conclude that the inner voice is in fact an epiphenomenon, which results from the way in which children learn to read (e.g., Watson, 1919). That is, children learn to read by sounding out letters and reading aloud before they learn to read silently and independently; thus, the persistence of the inner voice might simply be due to the way in which the ability to read is first acquired. Under this view, the inner voice is simply a persistent habit that is retained despite serving no real function. Or it might only be used by beginning and less skilled readers, while serving no major function for skilled adult reader during silent reading, except maybe when processing low-frequency words (Seidenberg et al., 1984; Waters et al., 1985, 1984). Indeed Hardyck and Petrinovich (1969) went so far as to suggest that the inner voice actually hinders fluent reading and suggested treatment programs for children who subvocalized during reading. Support for this view comes largely from studies that have failed to find effects of phonological coding where it was predicted that such effects would exist if phonological coding were involved (for a discussion, see McCusker et al., 1981).

Contrary to the position of Hardyck and Petrinovich (1969), there is substantial evidence to suggest a crucial link between phonological awareness (i.e., the knowledge of the internal sound structure of words), phonological coding, and success in learning to read across multiple languages (for reviews, see Ashby & Rayner, 2006; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001). Indeed, in his influential self-teaching hypothesis, Share (1995) termed phonological recoding the sine qua non of reading acquisition—allowing a reader to identify an unknown written word by translating it into its spoken counterpart (i.e., sounding it out), resulting in the acquisition of word-specific orthographic knowledge as an association is formed between the written and spoken forms (see also de Jong, Bitter, van Setten, & Marinus, 2009; Jorm & Share, 1983; Share, 2008). Importantly, the view that phonological coding in adult readers is merely an epiphenomenon resulting from the way children learn to read does not imply that phonological coding serves no function for beginning readers or adults reading unknown, low-frequency words. Rather, it claims that any persistence of the inner voice in skilled adults reading familiar words is an unnecessary carryover and epiphenomenal in nature.

If the inner voice were simply an epiphenomenon, then it would necessarily serve no functional purpose for the skilled adult reader, even though it might be activated (as a byproduct of the reading process) and even influence processing (M. Coltheart et al., 1977). However, we have already seen evidence that interfering with the inner voice disrupts the normal reading process (e.g., Daneman & Newson, 1992; Slowiaczek & Clifton, 1980), thus challenging its epiphenomenal status. Furthermore, if successful reading could occur without phonological coding, then we should expect to find a lesser incidence of phonological coding in languages that do not represent phonology to the same extent as English and other alphabetic languages. Contrary to this prediction, there is evidence for early phonological coding during the reading of Chinese, a logographic orthography (e.g., Zhang, Perfetti, & Yang, 1999; for reviews, see Halderman et al., 2012; Tan & Perfetti, 1998), and Hebrew, which does not represent most vowel information (e.g., Frost, 1995; Frost & Yogev, 2001). Finally, the most compelling evidence against the view that phonological coding is an epiphenomenon would be a demonstration of phonological coding during reading in a person who did not learn to read by first reading aloud and sounding out the letters. Prelingually, profoundly deaf readers whose first language is American Sign Language (ASL) or some other sign language offer the perfect test case to investigate this alternative. As the critical test case, phonological coding in deaf readers is the focus of this section.

Phonological Coding in Deaf Readers

Short-term memory research provides some evidence that prelingually, profoundly deaf individuals can use phonological codes (Engle, Cantor, & Turner, 1989; Hanson, 1982; Hanson & Lichtenstein, 1990) and that the use of phonological codes in such tasks is characteristic of good deaf readers but not poor deaf readers (Conrad, 1979; Hanson, Liberman, & Shankweiler, 1984; Hanson & Lichtenstein, 1990). Additionally, there is evidence that sign can serve as a memory code, as deaf subjects exhibit intrusion errors based on the formational properties of to-be-remembered signs, paralleling English phonological intrusion errors (e.g., Bellugi, Klima, & Siple, 1975; Hanson, 1982; Krakow & Hanson, 1985; Shand, 1982). Even so, there is still a question of whether deaf readers make use of phonological codes during reading, and if so, whether these codes are based on English phonology or ASL phonology (or fingerspelling). Although the short-term memory results hint that deaf signers of ASL might rely more heavily on ASL phonological codes, there is also evidence that the presentation modality can affect the type of code used and that proficient readers of English might not translate into an ASL code when they are presented with English stimuli (e.g., Hanson, 1982; Krakow & Hanson, 1985).

Early work examining the use of phonological codes during reading by deaf individuals relied heavily on proofreading and letter detection tasks and yielded mixed results, due to variable levels of control. K. Chen (1976) found no difference in deaf proofreaders' detection of silent versus pronounced *e*s, and Locke (1978) found no difference in target letter detection by deaf children as a function of target letter pronunciation (e.g., the *g* in *rag* vs. *rage*). As both phenomena yield significantly different processing in hearing individuals (e.g., Corcoran, 1966), these results were taken as evidence that deaf readers do not use phonological codes during reading (at least not English phonological codes). However, controlling for the position of the target letters, Dodd (1987) did find differences in target letter detection by deaf children as a function of pronunciation, as did Quinn (1981) when controlling word frequency. Beyond providing conflicting results, the proofreading and letter detection tasks are likely not very good tests of phonological code use during normal reading, as the goals of these tasks are quite distinct from the comprehension goal of normal reading and can result in different reading speeds and patterns of fixation data during reading (e.g., Kaakinen & Hyönä, 2010; Schotter, Bicknell, Howard, Levy, & Rayner, 2014; Spragins, Lefton, & Fisher, 1976).

In an attempt to avoid these potential confounds, Hanson, Goodell, and Perfetti (1991) had subjects perform semantic acceptability judgments for tongue twisters and control sentences. Additionally, they varied whether the subjects were under a concurrent memory load (remembering strings of numbers) and whether the memory load numbers were phonetically similar or dissimilar to the tongue twister. They found that both hearing controls and deaf subjects produced more errors on the semantic acceptability task when reading tongue twisters than control sentences. Additionally, both groups also made more errors when the tongue-twister sentences were phonetically similar to the concurrent memory load numbers. These results suggest that even profoundly, prelingually deaf readers may use English phonological codes during silent reading.

In a meta-analysis of reading achievement as it relates to phonological coding and awareness (PCA) in deaf readers, Mayberry, del Giudice, and Lieberman (2011) found that PCA accounted for only 11% of the variance in reading ability. Additionally, they found that the effect size did not show systematic variation in relation to reading level (i.e., beginning readers did not show a larger effect than advanced readers or vice versa) but instead remained highly variable across grade levels. This, they claim, is consistent with the idea that some deaf readers use PCA, whereas others adopt different coding strategies, and that there is no clear advantage to adopting one strategy over another.

In later work, Bélanger, Baum, and Mayberry (2012) directly compared the use of phonological and orthographic codes by skilled deaf readers, less skilled deaf readers, and hearing controls across two tasks designed to test prelexical (masked priming in lexical decision with primes that overlapped with the target in orthography and phonology (O+P+), overlapped only in phonology (O–P+), overlapped in neither orthography nor phonology (O–P–), or were unrelated) and postlexical (serial recall task) code use. Across both tasks they found no evidence for the use of French phonological codes by either the skilled or less skilled deaf readers (no difference in lexical decision latencies following O–P– and O–P+ primes, and no interference from phonologically similar items in serial recall). Instead they observed a reliance on orthographic codes for word recognition (faster lexical decision latencies following O+P+ than O–P+ primes) and short-term memory maintenance (better recall of words from O+P+ lists than O–P+ lists). Relatedly, both skilled and less skilled deaf readers show orthographic preview benefit but not phonological preview benefit during English sentence reading (Bélanger, Mayberry, & Rayner, 2013).

Potentially, deaf readers are in fact recoding the visually presented French (or other spoken alphabetic languages) into sign and using this visual and/or manual phonological code during reading. Indeed, several studies have produced evidence that deaf readers recode written English into sign (e.g., Liben & Drury, 1977; Lichtenstein, 1998; Moulton & Beasley, 1975; Odom, Blanton, & McIntyre, 1970). However, the previous studies all employed a working memory component, making it impossible to determine whether these codes are used during normal reading or only strategically to bolster memory performance. Two additional studies used tasks without an overt memory component. Morford, Wilkinson, Villwock, Piñar, and Kroll (2011) had prelingually deaf signers who were proficient English readers (reading grade level 8.9 or higher) perform a semantic relatedness judgment to pairs of English words that critically either shared aspects of sign phonology (hand shape, orientation, movement, or location) or were unrelated in ASL. Results showed that subjects were faster to accept pairs of related English words that shared phonologically related ASL translations and were slower to reject pairs of unrelated English words that shared phonologically related ASL translations. This demonstrates that proficient deaf readers activate ASL signs while processing written English and suggests that although deaf readers do not seem to rely on English phonological coding during reading, they may in fact rely on ASL phonological coding. Unfortunately, the nature of the semantic relatedness task does not reveal any information about the time course of this coding. It might be prelexical and aid in word recognition (e.g., a system where English orthography maps onto ASL signs and can aid in semantic representation activation), or it might only come online after lexical access (e.g., semantically mediated) to aid in short-term memory and comprehension. Although the specific task used in this study did not require any memory or comprehension component, if postlexically recoding into ASL to aid short-term memory occurs during normal reading, it might have been more or less an automatic process for the proficient readers in the study.

Treiman and Hirsh-Pasek (1983) had hearing English speakers and second-generation deaf signers perform semantic acceptability judgments to sentences. To test encoding strategies, they varied whether the sentences contained homophones, "finger twisters" (English sentences that if recoded into fingerspelling would contain confusing sequences), or "hand twisters" (English sentences that if recoded into ASL would contain many formationally similar signs). They found that hearing English readers showed evidence of English phonological coding (more errors to sentences containing homophones) and that deaf readers showed evidence of sign recoding (more errors to hand-twister sentences, also known as "finger fumblers"; Klima & Bellugi, 1979). Although providing additional evidence for sign recoding during sentence reading, these results again do not shed light on the time course of sign recoding, leaving open the question of whether this form of phonological coding is used for lexical access or comes online after lexical access to aid short term memory.

The results, then, are mixed, with some research suggesting the deaf readers use English phonological codes (e.g., Hanson et al., 1991), other research suggesting that they do not use English (or French) phonological codes (Bélanger et al., 2012; Bélanger et al., 2013), and still other research suggesting that they instead use ASL phonological codes (e.g., Morford et al., 2011; Treiman & Hirsh-Pasek, 1983). Additionally, although there is some evidence to suggest that deaf readers are not generating English (or French) phonological codes prelexically (e.g., Bélanger et al., 2012; Bélanger et al., 2013), there has been very little research specifically examining early phonological coding in deaf readers. Indeed, evidence for ASL coding comes from studies using semantic and sentence acceptability judgments, the results of which could have been influenced by postlexical codes (e.g., Morford et al., 2011; Treiman & Hirsh-Pasek, 1983). Future research should use online measures (such as eye-tracking) to assess, for example, whether there is evidence during reading for processing disruption in early measures on the critical words in finger fumblers. If deaf readers are recoding into sign phonology prelexically to aid in word identification, then there should be evidence of processing disruption in early eye movement measures. If there is no evidence of disruption in the early eye movement record, then perhaps deaf readers are not recoding into sign until after lexical access has been achieved. In this case the mapping might not be from English orthography to sign phonology; rather, lexical access may be achieved through a direct route from orthography to meaning (Bélanger et al., 2012; Bélanger et al., 2013) followed by semantically mediated recoding into ASL.

Taken together with the results from the reading of Chinese and Hebrew, the data suggest that phonological coding persists even if the orthography only partially represents (e.g., Chinese and Hebrew) or doesn't represent at all (e.g., English orthography for ASL signers or French orthography for signers of Quebec Sign Language) the phonology of the spoken/signed language of the reader. This further challenges the position that phonological coding is an epiphenomenon that persists after first learning to read by sounding out the words (i.e., coding aloud). The data suggest instead that phonological coding serves a role for deaf readers, at least for the purpose of maintaining information in working memory. Until future research determines how early these codes are being generated, it remains unclear whether they may aid word identification as well.

Summary

As laid out in the introduction, there are generally three proposed roles for phonological coding during reading: (a) that the codes come online early and can aid lexical access; (b) that the codes come online during or after lexical access and aid short-term memory and comprehension; and (c) that they subserve learning to read but are largely epiphenomenal in the skilled, adult reader. By reviewing the extensive literature from the naming of single words to the comprehension of lengthy passages, I hope I have demonstrated a clear involvement of phonological coding both prelexically and postlexically, as well as the fact that the prelexical–postlexical dichotomy is more or less a false one. That is to say that phonological coding can begin before a word is even fixated and goes on to form a more speech-like, complete code that restores prosodic and intonational information to the orthographic code and helps to maintain verbatim word order and semantic information in short-term memory while thoughts and sentences are integrated. However, the evolving nature of the code (e.g., level of abstractness, engagement of vocal musculature, etc.), from early activation during parafoveal preview to complete short-term memory representation, is less well characterized. Additionally, the finding that prelingually, profoundly deaf individuals use phonological codes (whether English or ASL) demonstrates quite conclusively that phonological coding is more than an epiphenomenon.

Examining the varying methodologies that have been employed to study phonological coding and the inner voice reveals that many diverge in several respects from the normal reading process, result in reaction time data that reveal very little about online processing, and/or involve additional processing demands that may alter or disrupt the normal reading process. Although these avenues of research have certainly provided a great amount of evidence for the fact that phonological information can influence the reading process, drawing additional conclusions about the necessity or nature of phonological codes using these methods is difficult. Future research should aim to approximate the normal reading process and should use sensitive, online measures of processing (e.g., eye-tracking, ERP) when possible. Furthermore, in order to better understand what aspects of reading require the use of phonological codes, a new, unobtrusive method of denying their use should be developed (e.g., using TMS). Indeed, gaining a better understanding of what the reading process looks like when phonological coding cannot proceed normally may give us further insights into the underlying causes of reading disorders and help to adjudicate between the current models of word identification that were outlined in the introduction (or lead to the creation of new models).

Reconsidering these models of word identification in light of the literature reviewed here is informative, but there are still unanswered questions that make it impossible to say definitively that any current model is supported by the data. Even so, there are aspects of the data that are more difficult for certain models to account for. For instance, there is substantial evidence across a number of methods for the early generation of phonological codes during reading (e.g., within 80–100 ms or the first fixation on a word), a fact that is difficult for the dual-route model to account for, since it argues for a reliance on direct meaning access, with phonological codes only being assembled for low frequency words or novel words. However, just because phonological codes are being generated, does not necessarily implicate them in the lexical access process. Hopefully future work can more effectively examine the reading process when phonological coding is denied (e.g., using TMS rather than articulatory suppression) to determine if phonological coding is necessary for lexical access as the activation–verification model would suggest, or if the codes are simply generated in parallel but not required for lexical access, in accordance with the parallel distributed processing model.

In conclusion, there is considerable evidence for the involvement of phonological information during the reading process, and the influence of this information on all stages from word identification to passage comprehension. Nonetheless, questions still exist. What does the reading process look like without the ability to use phonological codes? How abstract is the initial code? When and how does the phonological representation change as information is added to the code (e.g., prosodic information, intonational information, etc.)? What kinds of phonological codes are deaf readers using to achieve lexical access? Are these the same codes that deaf readers use to bolster short-term memory? The answers to these questions, as well as others regarding phonological coding and the inner voice, will bring us closer to a complete understanding of the normal reading process and the representations that subserve it.

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