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Reading Acquisition, Developmental Dyslexia, and Skilled Reading Across Languages: A Psycholinguistic Grain Size Theory

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The development of reading depends on phonological awareness across all languages so far studied. Languages vary in the consistency with which phonology is represented in orthography. This results in developmental differences in the grain size of lexical representations and accompanying differences in developmental reading strategies and the manifestation of dyslexia across orthographies. Differences in lexical representations and reading across languages leave developmental "footprints" in the adult lexicon. The lexical organization and processing strategies that are characteristic of skilled reading in different orthographies are affected by different developmental constraints in different writing systems. The authors develop a novel theoretical framework to explain these cross-language data, which they label a *psycholinguistic grain size* theory of reading and its development.

Reading is the process of understanding speech written down. The goal is to gain access to meaning. To acquire reading, children must learn the code used by their culture for representing speech as a series of visual symbols. Learning to read is thus fundamentally a process of matching distinctive visual symbols to units of sound (phonology). In most languages, the relationship between symbol and sound is systematic, whereas the relationship between symbol and meaning is arbitrary. For example, in English, the symbol *D* is almost always pronounced /d/. A child learning to read English can exploit regularities like this to access the phonology of words. In contrast, knowing that a word starts with the letter *D* tells the child nothing about its meaning. The first steps in becoming literate, therefore, require acquisition of the system for mapping between symbol and sound. Mastery of this system allows children to access the thousands of words already present in their spoken lexicons. The process of learning and applying these mappings has been called *phonological recoding*.

Phonological recoding has often been considered to be the sine qua non for successful reading acquisition. This is because it functions as a self-teaching device, allowing children successfully to recode words that they have heard but never seen before (Ehri, 1992; Share, 1995). For phonological recoding to be successful, children need to find shared grain sizes in the symbol system (orthography) and phonology of their language that allow a straightforward and unambiguous mapping between the two domains. The phonological system is already structured prior to reading, and therefore the quality and grain size of phonological representations prior to reading is likely to play a role in reading acquisition (Elbro & Pallesen, 2002; Perfetti, 1992; Wydell & Butterworth, 1999). In Part I of this article, we review what is currently known about phonological development in different languages prior to reading.

We then argue that beginning readers are faced with the following three problems: availability, consistency, and granularity of spelling-to-sound mappings. These problems are illustrated in Figure 1. The *availability problem* reflects the fact that not all phonological units are consciously (explicitly) accessible prior to reading. Thus, connecting orthographic units to phonological units that are not yet readily available requires further cognitive development. The *consistency problem* reflects the fact that some orthographic units have multiple pronunciations and that some phonological units have multiple spellings (Glushko, 1979; Seidenberg & McClelland, 1989; Ziegler, Stone, & Jacobs, 1997). Both types of inconsistency are assumed to slow reading development. It is important to note that the degree of inconsistency varies both between languages and for different types of orthographic units. This variation makes it likely that there will be differences in reading development across languages. Finally, the *granularity problem* reflects the fact that there are many more orthographic units to learn when access to the phonological system is based on bigger grain sizes as opposed to smaller grain sizes. That is, there are more words than there are syllables, more syllables than there are rimes, more rimes than there are graphemes, and more graphemes than there are letters. Reading proficiency depends on the resolution of these three problems (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001). The efficiency with which these problems can be solved seems to vary across languages and, we argue, should predict reading acquisition in different languages. In Part II of this article, we summarize the cross-language data currently available from studies investigating similarities and differences in reading development across orthographies.

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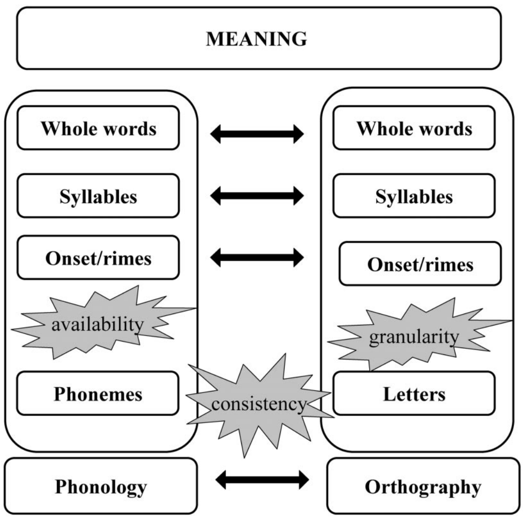

Figure 1. Schematic depiction of the three main problems of reading acquisition: availability, consistency, and granularity.

In all languages studied so far, a group of children (probably around 5%) experiences severe reading problems (developmental dyslexia) despite normal intelligence, good educational opportunities, and no obvious sensory or neurological damage (Snowling, 2000). It is still not agreed whether developmental dyslexia is the same phenomenon across different languages. In Part III of this article, we review cross-language data from studies investigating the causes and manifestations of dyslexia across different languages and writing systems. We argue that although the manifestation of dyslexia differs by language, the underlying causes of dyslexia are universal and stem from impaired development of the phonological system. In Part IV of this review, we attempt to integrate the key results from each of these domains into a single theoretical framework. This *psycholinguistic grain size theory* puts special emphasis on the development and use of different grain sizes across visual and auditory domains and across languages. In Part V of this review, we discuss some implications of our theory for future research, and we investigate how the theory compares with other theoretical frameworks for describing phonological development, reading development, and skilled reading.

Part I. Phonological Development Prior to Reading Across Different Languages

The traditional way of investigating children's representation of the phonological structures characterizing their language has been via experimental measures of their *phonological awareness* skills prior to reading. Phonological awareness, also referred to as *phonological sensitivity*, comprises the ability to recognize, identify, or manipulate any phonological unit within a word, be it phoneme, rime,[1] or syllable (see Figure 2). Phonological awareness is strongly predictive of reading and spelling acquisition across languages (Bradley & Bryant, 1983; Bryant, MacLean, Bradley, & Crossland, 1990; Hoien, Lundberg, Stanovich, & Bjaalid, 1995; Lundberg, Frost, & Petersen, 1988; Schneider, Kuspert, Roth, Vise, & Marx, 1997). A large number of studies have shown that good phonological awareness skills characterize good readers, whereas poor phonological awareness skills characterize poor readers (for reviews, see Adams, 1990; Brady & Shankweiler, 1991; Goswami & Bryant, 1990; Scarborough, 1998; Wagner & Torgesen, 1987).

Sequential Development of Phonological Awareness

The emergence of phonological awareness can best be described along a continuum from shallow sensitivity of large phonological units to a deep awareness of small phonological units (Stanovich, 1992). The existence of such a developmental sequence has been demonstrated, for example, in the recent studies by Anthony and his colleagues that have made use of sophisticated statistical techniques such as confirmatory factor analysis and item response theory (Anthony & Lonigan, 2004; Anthony et al., 2002; Anthony, Lonigan, Driscoll, Phillips & Burgess, 2003). For example, Anthony et al. (2003) used a large group of participants (more than 1,000 children), a wider age range than previous studies (2–6 years), hierarchical loglinear analyses, and a factorial design that allowed them to investigate the order of acquisition of phonological sensitivity skills at various grain sizes while holding constant the type of operation that was performed (e.g., blending, deletion). The results clearly showed that children's progression of sensitivity to linguistic units followed the hierarchical model of word structure shown in Figure 2. That is, children generally mastered word-level skills before they mastered syllable-level skills, syllable-level skills before onset–rime skills, and onset–rime-level skills before phoneme-level skills, controlling for task complexity.

Studies across different languages have yielded a remarkably similar picture, despite differences in the phonological structure of the languages being learned. At least for normally progressing children, preschoolers typically demonstrate good phonological awareness of syllables, onsets, and rimes in most languages. Syllable awareness is usually present by about age 3 to 4, and onset–rime awareness is usually present by about age 4 to 5. Phoneme awareness only develops once children are taught to read and write, irrespective of the age at which reading and writing is taught (see Goswami & Bryant, 1990, for an overview). Illiterate adults tend to lack phoneme awareness skills (K. Lukatela, Carello, Shankweiler, & Liberman, 1995; Morais, Cary, Alegria, & Bertelson, 1979). A wide variety of phonological awareness tasks have been used across languages to explore this developmental sequence. The strongest research design for investigating phonological development gives the same phonological tasks to children learning different languages, ideally children who have been matched for IQ and receptive vocabulary across cultures. Although almost no studies have used such stringent cross-language matching, developmental findings within single languages show a high degree of convergence with respect to sequence.

For example, I. Y. Liberman, Shankweiler, Fischer, and Carter (1974) used a tapping task to measure the development of phono-

[1] The term *rhyme* is used to refer to judgments about phonology (e.g., as in *rhyme judgments*) and to the phonological unit of any word following the onset (e.g., r-abbit, t-opic). The term *rime* is used when this phonological unit refers specifically to the division of a single syllable (e.g., s-eam, str-eam). Because almost all phonological awareness tasks examining rhyme and phoneme awareness in children use monosyllables, we typically use the term *rime* to refer to this phonological unit.

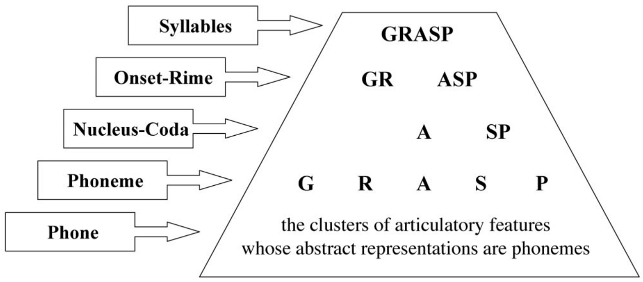

Figure 2. A schematic depiction of different psycholinguistic grain sizes.

logical awareness at the syllable and phoneme levels in normally developing American children. The children had to tap once for words that had either one syllable or phoneme (*dog*, *I*), twice for words that had two syllables or phonemes (*dinner*, *my*), and three times for words that had three syllables or phonemes (*president*, *book*). No 4-year-olds and only 17% of 5-year-olds could manage the phoneme version of the task, whereas 70% of 6-year-olds reached a criterion of six consecutive correct responses. Performance in the syllable version of the task was much better at all ages. Italian children tested by Cossu, Shankweiler, Liberman, Katz, and Tola (1988) showed almost identical patterns of performance. The majority of preschoolers (ages 4 and 5 years) could not manage the phoneme task (20% reached criterion), whereas older children already at school (7- and 8-year-olds) were very proficient (97% reached criterion). Criterion at the syllable level was reached by 67% of the 4-year-olds, 80% of the 5-year-olds, and 100% of the school-age sample.

Table 1 lists a number of studies that investigated syllable and phoneme counting tasks in different languages (Turkish, Italian, Greek, French, and English). As can be seen in Table 1, in all languages, syllable awareness is much better than phoneme awareness prior to literacy teaching. Phonemes are represented, usually very rapidly, once literacy is taught. It is interesting that although the developmental sequence is respected in all languages, there are quite big variations in the global levels of phonological awareness attained. Of course, this could simply reflect the lack of cross-language matching for factors like vocabulary acquisition and teaching practices in kindergarten. However, in our view, differences in the characteristics of the spoken language are a more plausible source of these developmental differences. For example, the Turkish kindergartners showed remarkable phoneme awareness skills for prereaders. Durgunoglu and Oney (2002) pointed out that properties of the spoken language (e.g., vowel harmony for pluralization) "force" Turkish children to notice phonemic changes in the spoken language prior to reading and that one consequence of this is that excellent letter–sound recoding skills typically develop by the 5th month in first grade despite teaching methods "going from the whole" (i.e., children begin to learn to read Turkish by memorizing sentences). Turkish, Greek, and Italian show high levels of syllable awareness prior to literacy and are also languages with a simple syllable structure (mainly consonant–vowel [CV], vowel–consonant [VC], vowel [V], and CV–consonant [C] syllables) and relatively limited vowel repertoires. In contrast, French and English have quite complex syllable structures with many consonant clusters and larger vowel repertoires, and children raised with these languages develop lower levels of syllable awareness prior to literacy.

Similar cross-language comparisons can be found for onset–rime awareness. Bradley and Bryant (1983) developed the oddity task to measure the development of onset and rime awareness. Children were given sets of three or four words and asked to spot the odd word out, that is, the word that was different in terms of either its initial sound ("bus, bun, *rug*"), its medial sound ("*pin*, bun, gun") or its final sound ("*doll*, hop, top"). These triples of words differed in terms of single phonemes, too, but related research showed that the oddity judgments were made on the basis of shared onsets (the initial sound task) or rimes (the medial and final sound tasks; see Kirtley, Bryant, MacLean, & Bradley, 1989). Bradley and Bryant (1983) found that 4- and 5-year-olds were very proficient at the oddity task, performing at above-chance levels in all versions, although rime awareness was easier than onset awareness. Performance with the onset version of the task was around 56% correct, whereas performance with the rime version of the task was around 71% correct. Very similar results have been reported for Dutch, German, and Chinese (De Jong & van der Leij, 2003; Ho & Bryant, 1997; Siok & Fletcher, 2001; Wimmer, Landerl, & Schneider, 1994).

The claim that phoneme awareness develops in response to literacy instruction or direct training is not without controversy, however (Hulme, 2002). One reason is that many phoneme awareness tasks require the child to delimit phonemes relatively precisely (e.g., by counting them), whereas a task like the oddity task requires the recognition of shared units and (it has been argued, e.g., by Morais, Alegria, & Content, 1987) can be solved on the basis of more global similarities. One way around such objections is to investigate the sequence of phonological development while holding task demands constant (see Anthony et al., 2003). Rather

Table 1
Data (% Correct) From Syllable and Phoneme Counting Tasks in Kindergarten and First-Grade Children Across Different Languages

		Kindergarten		First grade	
Language	Study	Syllable	Phoneme	Syllable	Phoneme
Turkish	Durgunoglu & Oney (1999)	94	67	98	94
Italian	Cossu et al. (1988)	80	27	100	90
Greek	Harris & Giannouli (1999)	85	0	100	100
French	Demont & Gombert (1996)	69	2	77	61
English	Liberman et al. (1974)	48	17	90	70

few studies have used the same phonological awareness tasks to measure onset–rime versus phoneme awareness in children. Goswami and East (2000) gave English 5-year-olds four tasks—a beginning sound oddity task, an end sound oddity task, a segmentation task, and a blending task—at both the onset–rime and phoneme level. For example, for the shared beginning sound oddity triple "glum, stick, glad," the shared sound was an onset, whereas for the oddity triple "glum, grab, stick," the shared sound was a phoneme. The children's performance was consistently better at the onset–rime level than at the phoneme level in all four tasks (e.g., onset oddity was 71% correct; initial phoneme oddity was 48% correct). Hulme et al. (2002) gave 5- and 6-year-olds three tasks at the onset–rime and phoneme level, detection, oddity, and deletion. Again, the phoneme measures were more difficult than the onset–rime measures (e.g., for the oddity task, the percentage of children scoring above chance was as follows: onset 60%, rime 60%, initial phoneme 47%, final phoneme 11%). Similar results have been reported when comparing onset–rime and phoneme segmentation and onset–rime and phoneme blending. Significantly better segmentation performance at the onset–rime level has been reported by Nation and Hulme (1997) for 6-year-olds (55% vs. 24%). Significantly better blending performance at the onset–rime level has been reported by McClure, Ferreira, and Bisanz (1996) for 5-, 6-, and 7-year-olds (69% vs. 49%).

One potential problem with all these comparisons is that onsets and rimes are usually larger units than single phonemes. For example, in Goswami and East (2000) and Hulme et al. (2002), the onsets in the oddity task were two phonemes long, and hence shared more similarity overall (glum, glad) compared with the phoneme-level comparisons (glum, grab). This potential confound between linguistic level and size of shared unit is difficult to avoid, as if unit size is equated, linguistic level is no longer manipulated (e.g., if single initial phonemes are used for stimuli, this initial phoneme is the syllable onset). A different approach to the question of whether the developmental sequence is an artifact of the overall phonological similarity of items is to control the words being used for this factor. Carroll and Snowling (2001) gave 3- and 4-year-old children a rhyme matching task in which distractors were matched for global phonological similarity to the target (e.g., "house: mouse, horse"; "bell: shell, ball"). They reported that approximately 30% of the 3-year-olds, 60% of the young 4-year-olds, and 76% of the 4.5-year-olds scored above chance in matching rimes, even though many distractors were as phonologically similar to the targets as the correct rime choices. They concluded that there "appears to be a natural superiority of rime over phoneme segmentation" (Carroll & Snowling, 2001, p. 339).

In summary, at least for the European languages tested to date, there seems to be a developmental progression in the phonological domain from larger to smaller units. The most accessible phonological units for the truly beginning reader are large units. Full access to phonemes only develops once children are taught to read and write, irrespective of the age at which reading and writing is taught. Further research within this developmental framework is now required across languages.

Some Controversial Issues

There are at least four issues that have been controversial in the literature on phonological development and its relation to reading. The first issue concerns the idea of a universal developmental progression from large to small phonological units. The second issue is the question of whether the intrasyllabic division of onset and rime is universal. The third issue concerns the question of whether the phonological representations developed by young children are really that different from those of adults. Finally, the last issue is related to the claim that phonological awareness is causally related to reading acquisition.

Is the developmental progression from large units to small units? Some authors have argued that awareness of small phonological units (phonemes) comes before—or at least does not come after—awareness of larger phonological units (Duncan, Seymour, & Hill, 1997; Hulme, 2002; Seymour, Duncan, & Bolik, 1999; Seymour & Evans, 1994). Although the studies by Seymour and his colleagues have received attention, it is important to emphasize that they are not representative of the wider literature in claiming that phonemes are available early in explicit segmentation tasks. This claim rests particularly on a novel task designed by these researchers for 5-year-olds, the common unit task (Duncan et al., 1997). In the common unit task, children have to say aloud the sound shared by two words. This sound can be the onset (e.g., "can–couch," /k/), the rime (e.g., "can–man," /æn/), or a phoneme (e.g., "can–hat," /æ/). Although performance with the onset was good in Duncan et al.'s (1997) study (73% correct), performance with the rime unit (14% correct) was significantly poorer than performance with phonemes (44% correct). Children's poor performance at the rime level in this novel task was given a strong theoretical interpretation by Duncan et al. (1997): "The data . . . run counter to the progressive view that explicit phonological awareness develops for the larger onset and rime units before smaller phonemic units" (p. 198).

However, these unusual findings may also reflect the cognitive demands imposed by the novel common unit task. When Goswami and East (2000) attempted to replicate Duncan et al.'s (1997) findings, they noted that young children found the common unit task confusing, because whereas some parts of it reflected what the children were learning about reading in school (e.g., isolating initial sounds), others did not. The children were particularly unclear about what to do in the rime version of the task, which was dissimilar to anything that they had done before. Goswami and East therefore gave their 5-year-olds some literacy tuition at the onset–rime level, focusing on rhyme analogies (*jet–net*, *kiss–hiss*, *rock–sock*). Following this tuition, the children became able to do the common unit task at the rime level, scoring 52% correct (compared with 17% correct in a pretest). For phonemes, performance was 38% correct (compared with 29% correct at pretest). Hence, once children understand the tasks they are being given, the developmental progression appears to be preserved.

Bertelson, de Gelder, and van Zon (1997) also investigated Duncan et al.'s (1997) claims, using a deletion task with Dutch kindergarteners and first- and second-graders. They also found evidence supporting the onset–rime precedence. Those children found it easier to delete an initial consonant when it was an onset (CVCC items) than when it was part of a consonant cluster (CCVC items). Bertelson et al. (1997) concluded, "The results obtained . . . contradict the disjoint developmental proposal of Seymour and Evans (1994)" (p. 8). In contrast, Geudens and Sandra (2003) used a segmentation task with Dutch children of the same ages and did not find evidence for onset–rime precedence. In their study, there was an advantage for segmenting VC units (rime segmentation) over CV units (onset–vowel segmentation, which should be easier) for items using plosive (71% correct vs. 62% correct) and fricative (70% correct vs. 61% correct) consonant phonemes. However, for items using nasal (60% correct vs. 58% correct) and liquid (59% correct vs. 57% correct) phonemes, no differences were found. Again, the data were given a strong interpretation by the authors, who argued that their data "consistently failed to support the special role of the onset-rime structure" (Geudens & Sandra, 2003, p. 171) of the syllable for Dutch.

Task factors again seem the most likely explanation of these discrepant results. It is generally accepted that young children can detect phonological units before they can manipulate them (see, e.g., Anthony et al.'s (2003) study of more than 1,000 children). In general, studies find that when children can perform segmentation tasks, onset–rime segmentation is easier than phoneme segmentation (Greaney, Tunmer, & Chapman, 1997; Stahl & Murray, 1994). Geudens and Sandra (2003) reported that their segmentation task was too demanding for their younger participants and so was a substitution task that they tried with the older children. In these circumstances, a useful developmental strategy is to add a detection task based on the same items. For example, Goswami and East (2000) used the same items from the common unit task to create a same−different judgment task (judging whether pairs of words like *can* and *hat* shared a sound). The same children who struggled with the common unit task now showed excellent performance in judging onsets and rimes (88% and 90% correct, respectively). They also performed better with onsets and rimes than with phonemes (74% correct). Clearly, not all phonological awareness tasks are equal.

Finally, when assessing studies of phonological awareness with respect to sequence, it is important to ensure that the child has the cognitive capacity required for the particular tasks being used and that measurement problems like floor effects, ceiling effects and low reliabilities have been attended to. This point is nicely demonstrated by Anthony and Lonigan (2004), who used confirmatory factor analysis and structural equation modeling to more precisely quantify the longitudinal relations among phonological skills. Their analyses included data sets from four studies used by their original authors to argue for the preeminence of the phoneme (Muter, Hulme, & Snowling, 1997; Muter, Hulme, Snowling, & Taylor, 1997) and overall incorporated 1,189 children from 3 to 7 years old. Their results indicated that sensitivity to syllables, onsets, and rimes were as much a part of the construct of phonological awareness as sensitivity to phonemes and that conclusions to the contrary were due to ignoring floor effects and the inappropriate use of exploratory factor analysis. Anthony and Lonigan (2004) concluded,

> In summary, it appears that the debate over whether sensitivity to rhyme or sensitivity to phonemes is most important for reading and spelling has led researchers and theorists astray . . . The important question . . . is not what type of phonological sensitivity is most important for literacy but which measures of phonological sensitivity are developmentally appropriate for this particular child. (p. 53)

Our own analyses of existing studies certainly support this conclusion.

Is the intrasyllabic division of onset and rime a linguistic universal? The second controversial issue is whether the onset–rime division of the syllable is preferred by children across all languages. It is quite likely that in some languages, phonological rimes are no more salient or are actually less salient than other types of large units (e.g., onset–vowel units, also referred to as *bodies*). For example, speech perception data from Japanese adults suggest that Japanese follows a moraic structure, in which the preferred units are onset–vowel (morae). Although in general morae correspond to CV syllables, some syllables include special sounds that constitute separate morae in Kana (e.g., certain nasals, geminates, long vowels, and "dual" vowels; see Tamaoka & Terao, 2004). Hence the special sounds can create two morae when there is only one syllable. An example is the Japanese loan word for the trisyllable *calendar*, /kareNdaR/. In Kana, this word has five morae: /ka re N da R/. Inagaki, Hatano, and Otake (2000) investigated whether preschool Japanese children would show a preference for moraic or syllabic representation by using stimuli incorporating these special sounds. They also studied older Japanese children who were learning to read Kana. They suggested that once Kana acquisition had begun, any early preference for syllabic representation might shift to a preference for moraic representation.

The children (4- to 6-year-olds) were asked to make dolls jump along a path of stepping stones (colored circles) in time with their articulation of familiar words. All the practice trials were composed of words sharing the same number of syllables and morae (e.g., "kani" [crab], 2 syllables and 2 morae). The experimental trials incorporated stimuli using the special sounds. The data essentially revealed a shift from a mixture of syllabic and moraic segmentation in the preschoolers to moraic segmentation in the readers. As even preschoolers may know some Kana (Tamaoka & Terao, 2004), it is not clear when morae become preferred representational units. However, it is clear that an onset–rime division of the syllable appears irrelevant to Japanese. Similar results have been reported in Korean. In one of their experiments, Yoon, Bolger, Kwon, and Perfetti (2002) presented English and Korean students with identical pairs of spoken syllables and asked them to make similarity judgments. English students rated the syllables as more similar if they shared the rime, whereas Korean students rated the same syllables as more similar if they shared the body. Yoon et al. further showed that Korean children appeared to prefer CV body units in reading, decoding both Korean and English nonwords more accurately in Goswami's (1986) analogy task when they shared the CV body than when they shared the VC rime. Decoding by analogy tasks produce a preference for onset–rime structure in English-speaking children (Goswami, 1991, 1993).

Even within languages sharing an onset–rime syllable division, features of the spoken language affect phonological development. As noted earlier, the rules for pluralization in Turkish make children very aware of vowel phonemes within the rime unit (via vowel harmony; Durgunoglu & Oney, 1999). A very similar point has been made in comparing Czech and English. Caravolas and Bruck (1993) reported that Czech children found it significantly easier to delete the first consonant phoneme in a nonword with a cluster onset (e.g., /k/ in "krin"; 86% correct) than did Canadian children (39% correct). They argued that as spoken Czech has a large number of consonant cluster onsets, Czech children were more aware of individual phonemes within clusters than English-speaking children. These studies suggest that the phonological characteristics of the spoken language have a significant effect on

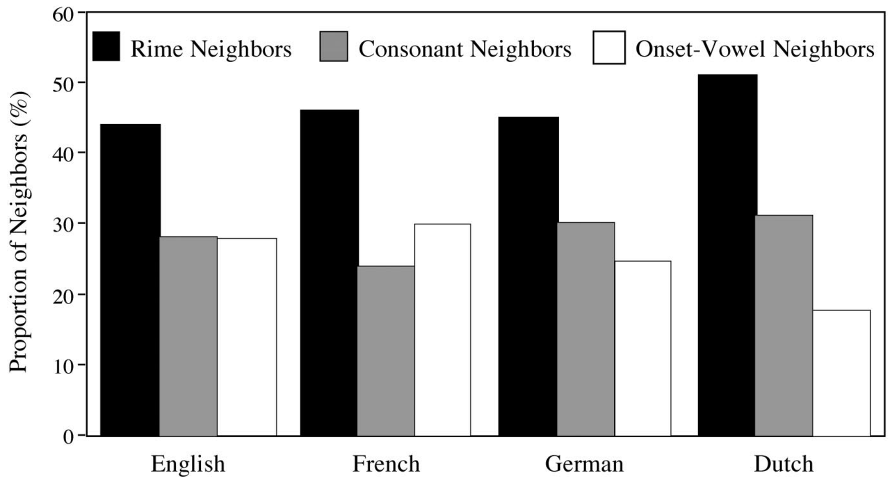

Figure 3. Statistical distribution of rime neighbors (_VC), onset–vowel neighbors (CV_), consonant neighbors (C_C) in English, French, German, and Dutch.

phonological development. Depending on these characteristics, a preference for body–coda segmentation rather than onset–rime segmentation of the syllable may be found. If the idea that the emergence of salient phonological units depends on the particular characteristics of the spoken language is accepted, then it should be possible to define a priori at least some of the factors that may influence phonological development.

One prediction is that languages in which onset–rime segmentation of syllables is preferred (e.g., German, Dutch, English, French) should exhibit greater phonological similarity at the rime than at the onset–vowel level. In language acquisition, children need to extract underlying structure from a complex environment of sounds that have "deep" systematic regularities organized at different levels. Structural regularities present in the lexicon of spoken word forms (such as neighborhood similarity characteristics) may form the basis of incidental learning about phonology, just as statistical regularities present in sequences of syllables (phonotactic and transitional probabilities) are thought to form the basis of word segmentation and learning (e.g., Saffran, Newport, Aslin, Tunick, & Barrueco, 1997).

This possibility can be tested empirically by comparing the percentage of rime neighbors, onset–vowel neighbors, and consonant neighbors for English, German, French, and Dutch.[2] For a target word like *cot*, *pot* would be a rime neighbor, *cop* would be an onset–vowel neighbor, and *kit* would be a consonant neighbor (see De Cara & Goswami, 2002). As a first approximation, we simply calculated the proportion of rime, onset–vowel, and consonant neighbors among all phonological neighbors. The English, German, and Dutch analyses were based on the monosyllabic words in the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993), the French analyses were based on the monosyllabic words in BRULEX (Content, Mousty, & Radeau, 1990). These data are presented in Figure 3. The analysis shows that rime neighbors predominate in English, French, Dutch, and German phonology. Thus, if phonological similarity between spoken words is a developmental factor contributing to the emergence of awareness of different phonological units in different languages (DeCara & Goswami, 2003), then it is not surprising that rimes acquire a special status in these languages during phonological development. Analogous similarity-based analyses of the phonological neighborhood structure of languages such as Korean and Japanese would be extremely interesting.

Are young children's phonological representations really so different from adults'? A third area of controversy is whether the phonological representations developed for comprehending and producing spoken language are really so different from those found in literate adults. It is well known that infants discriminate the acoustic elements that yield phones from birth onward (e.g., Eimas, Siqueland, Jusczyk, & Vigorito, 1971). There is also extensive developmental evidence from studies of speech perception and production showing that young children appear to have fine-grained levels of phonological representation in certain circumstances, including syllable, segment, and feature-level information (e.g., Gerken, Murphy, & Aslin, 1995; Gierut, 1998; Gierut, Morrisette, & Champion, 1999; Jusczyk, 1999). Slips of the tongue in young children involve whole segments (e.g., Stemberger, 1989), and detailed case studies of phonetic inventories show that by age 3, children with large lexicons have large inventories of individual features, syllable shapes, and stress placements (Stoel-Gammon, 1998). Data like these raise the question of whether it is correct to argue that phonological representations really incorporate increasingly finer grain sizes with development. If infants and young children can discriminate phones, surely they can also access phonemes?

Part of this controversy is due to a confusion between phones and phonemes. The ability to distinguish the phonetic features that make /ba/ different from /pa/ is not the same as the ability to categorize the shared sound in *pit*, *lap,* and *spoon* as the phoneme /p/ (see Swingley & Aslin, 2000). It is the latter ability that develops with literacy (after all, illiterate people comprehend spoken language perfectly well but tend to lack phoneme awareness). The fact that infants seem to be able to appropriately discriminate

[2] These languages could be analyzed because computerized databases exist for these languages (CELEX and BRULEX).

the phonetic features of the languages they hear does not automatically lead them to develop the ability to label the phoneme category in the derived, evolutionarily nonadapted task of reading acquisition (see Gleitman, 1985). Nevertheless, it is likely that this ability developed automatically for some very phonologically sensitive individuals, such as the Phoenicians, who invented the first alphabet. In this context, it is interesting to note that Greek is a language with a relatively simple syllable structure in which many onsets and rimes are equivalent to single phonemes.

Is there a causal link between phonological awareness and reading? The enterprise of establishing empirical evidence for a causal link between a child's phonological awareness skills and his or her progress in reading and spelling has been called "a strikingly successful one" (Goswami & Bryant, 1992, p. 49; see also Adams, 1990; Lundberg, 1991; Stanovich, 1992; Torgesen et al., 1999). Nevertheless, perhaps surprisingly, there are still those who dispute that the link exists. For example, Castles and Coltheart (2004) recently argued that "no single study has provided unequivocal evidence that there is a causal link from competence in phonological awareness to success in reading and spelling acquisition" (p. 77). In a critical review, they considered and dismissed even those studies seen as particularly influential within the developmental arena (e.g., the large-scale studies by Bradley & Bryant, 1983; Bryant et al., 1990; Lundberg et al., 1988; Schneider et al., 1997). These studies have been considered particularly influential because (a) they used strong research designs whereby the nature of the studies was longitudinal; (b) they began studying the participants when they were prereaders; and (c) they tested the longitudinal correlations found between phonological awareness and literacy via intervention and training, thereby demonstrating a specific link that did not extend, for example, to mathematics.

In assessing the arguments used by Castles and Coltheart (2004) to eliminate even these strongest studies, it is instructive to consider the a priori assumptions that they made concerning phonological development and reading acquisition. Castles and Coltheart (2004) set out to test the status of "the original hypothesis that phonological awareness represents *a distinct set of spoken-language skills* [italics added] that (a) precede and (b) directly influence the process of reading acquisition" (p. 78). However, they then stated two assumptions that made the rest of their analyses largely irrelevant. These assumptions are that (a) the most basic speech units of a language are phonemes (p. 78) and (b) it is impossible to derive a pure measure of phonological awareness if a child knows any alphabetic letters (p. 84). In adopting these two assumptions, they diverged from the developmental literature. As demonstrated above, and indeed as argued for some time in the speech-processing literature (Greenberg, Carvey, Hitchcock, & Chang, 2003; Jusczyk, 1999; Warren, 1993), the most basic speech units of a language are syllables, not phonemes. Work with infants has suggested that the lexical system is set up initially on the basis of information about prosody, onsets, duration, and vocalic nuclei (e.g., Jusczyk, Goodman, & Baumann, 1999; Plunkett & Schafer, 2001; Trehub, Thorpe, & Morrongiello, 1987), all of which aid syllable extraction. Phones (in contrast to phonemes) may be processed early, but as documented above, letter learning is required for phonemic awareness to develop. Measures of phonological awareness in preschoolers are hence syllable, onset, and rime measures.

The adevelopmental criteria adopted by Castles and Coltheart (2004) led them to reject all the available developmental studies as unsuitable for assessing their version of the causal hypothesis. For example, Bryant et al.'s (1990) study was excluded because measures of phoneme awareness were not taken when the children were aged 4 years, only when they were aged 5 years (at 4 years, most English-speaking children are unable to solve phoneme awareness tasks; see, e.g., Anthony et al., 2002). Studies by Lundberg et al. (1988) and Schneider et al. (1997) were eliminated for including preschoolers who already knew four to five letters. Yet even 2-year-olds in literate societies tend to know the letters in their names and thereby probably know four to five letters. In our view, Castles and Coltheart (2004) were unable to find evidence for their version of the causal hypothesis about phonological awareness because (a) they had narrowed the focus to studies showing a causal link between phonemic awareness and literacy and (b) phonemic awareness must be demonstrated in prereaders who do not know any letters. It is not surprising, then, that Castles and Coltheart (2004) concluded that "no such study exists in the literature" (p. 105).

The essential point, of course, is that assessing phonemic awareness in preschoolers is not the correct way to test the developmental hypothesis. More recently, it has been shown that the links between phonological awareness and progress in literacy reported across languages for children are also found in studies of adults. Durgunoglu and Oney (2002) reported that Turkish adults enrolled in a literacy program had widely varying levels of phonological awareness. These varying levels of phonological awareness were significantly correlated with their reading and spelling abilities both before and after completing a 90-hr literacy training course. Again, as pointed out by others before us, the specific tasks and levels of linguistic complexity that best predict literacy depend on an individual's level of development, whether that individual is an adult or a child. Within the apparently universal sequence of development from awareness of large units to awareness of small units, floor effects, ceiling effects, task difficulty, and measurement artifacts can obscure the fundamental relationship between phonological sensitivity and reading and spelling.

Part II. Reading Acquisition Across Different Languages

Despite the similar developmental trajectory of phonological representation across many European languages, reading acquisition itself varies markedly across the very same languages. At least three factors seem crucial for explaining these cross-language differences: consistency of spelling-to-sound relations, granularity (grain size) of orthographic and phonological representations, and teaching methods.

The Importance of Orthographic Consistency

Spelling-to-sound consistency varies across orthographies (Frost, Katz, & Bentin, 1987). In some orthographies, one letter or letter cluster can have multiple pronunciations (e.g., English, Danish), whereas in others it is always pronounced the same way (e.g., Greek, Italian, Spanish). Similarly, in some orthographies, a phoneme can have multiple spellings (e.g., English, French, Hebrew), whereas in others it is almost always spelled the same way (e.g., Italian). It is relatively easy to learn about phonemes if one letter consistently maps onto one and the same phoneme or if one phoneme consistently maps to one and the same letter. It is relatively difficult to learn about phonemes if a letter can be pronounced in multiple ways (e.g., the letter *A* in English, which maps onto a different phoneme in the highly familiar words *cat*, *was*, *saw*, *made*, and *car*). It is also difficult to learn about phonemes if a phoneme can be spelled in multiple ways. Phonemes can be spelled in multiple ways in many languages, which is one of the main reasons why spelling development lags behind reading development in languages that exhibit high degrees of spelling inconsistency, such as Hebrew, French, or English (Bosman & Van Orden, 1997; Geva, Wade-Woolley, & Shany, 1993; Sprenger-Charolles, Siegel, & Bonnet, 1998).

This analysis suggests that reading acquisition should be more rapid in orthographies in which letter–sound relationships are highly consistent. Indeed, a number of monolingual studies carried out in relatively consistent writing systems have reported high accuracy scores for recoding words and nonwords toward the end of Grade 1. For example, Greek children read on average 90% of real words correctly compared with 89% for nonwords (Porpodas, Pantelis, & Hantziou, 1990). Italian children read on average 94% of real words correctly compared with 82% for nonwords (Cossu, Gugliotta, & Marshall, 1995). French children read about 87% of words and 80% of nonwords correctly (Sprenger-Charolles et al., 1998). Even in a Semitic language, such as Hebrew, decoding accuracy was found to be around 80% at the end of Grade 1 (see Share & Levin, 1999). Note that Hebrew children learn to read pointed Hebrew, which has almost perfect grapheme-to-phoneme correspondences. These quite high accuracy scores for phonological decoding stand in sharp contrast to the performance of English children a year later, at the end of Grade 2 (Share & Levin, 1999). English has very inconsistent grapheme–phoneme relations, and in a representative study, children learning to read English scored no more than 70% correct in word reading and 45% correct in nonword reading (Frith, Wimmer, & Landerl, 1998).

One problem with monolingual studies is that item characteristics and subject variables often differ from one study to another. Cross-language studies that control for such variables are thus particularly important. A number of recent studies have investigated the development of grapheme–phoneme recoding skills in different languages in a controlled fashion. Goswami, Gombert, and de Barrera (1998) gave English, French, and Spanish 7-, 8-, and 9-year-old children matched for standardized reading age nonwords to read that could only be decoded by using grapheme–phoneme correspondences. The nonwords were constructed so that neither phonological nor orthographic rimes were familiar to the children (e.g., *zoip*, *koog*). This meant that all the constituent graphemes in each word had to be decoded individually and blended into an unfamiliar phonological string. The mean positional bigram frequencies of the nonwords were matched as closely as possible across languages. For monosyllables, the English 7-year-olds decoded on average 12% of these simple nonwords accurately compared with 53% for the French 7-year-olds and 94% for the Spanish 7-year-olds. By a reading age of 9 years, the English children decoded on average 51% of these nonwords correctly compared with 73% for the French children and 92% for the Spanish children. The differences in recoding accuracy approximately reflect the relative transparencies of the orthographies.

Frith et al. (1998) studied nonword reading in German and English 7-, 8-, and 9-year-old children. The German–English comparison is ideal in terms of matching items because both languages have similar orthography and phonology. For example, the words *ball*, *park*, and *hand* exist in both languages in identical form. These words differ quite dramatically in terms of the consistency of spelling-to-sound correspondences, however. The grapheme *a* receives the same pronunciation in all three words in German but a different pronunciation in each word in English. If orthographic consistency affects the development of grapheme–phoneme recoding strategies, then English children should be less efficient than German children at recoding nonwords that include graphemes like *a* (e.g., *grall*). Frith et al. found that the German children's nonword reading performance was already close to ceiling after as little as 1 year of reading instruction. In contrast, the reading accuracy of the English children was much lower and did not reach comparable levels until the children had experienced 3 years of reading instruction. When reading identical nonwords (e.g., *grall* [English]–*Grall* [German]), the 7-year-old English-speaking children made errors in the region of 55% compared with 15% for their German peers. In both language groups, performance improved with age, but differences were still marked at age 9. A significant difference in nonword reading was even found when only those German and English children whose word-reading performance was 100% correct were compared. The selected German children had an error rate of only 8% with nonwords based on these real words (as in *Grall–Ball*), whereas their English-speaking counterparts had an error rate of 22% (for similar results, see also Wimmer & Goswami, 1994; Wimmer & Hummer, 1990).

Another problem with these cross-language comparisons is that it is quite difficult to control for sociocultural differences across languages. For example, there may be differences in school systems, curricula, teaching methods, and demographic distributions. This problem has begun to be addressed. Bruck, Genesee, and Caravolas (1997) followed a group of English- and French-speaking children who were from the same area in Canada. They investigated word and nonword reading at the end of Grade 1 by using high-frequency regular monosyllabic words and nonwords. The results showed that the English-speaking children lagged behind the French-speaking children by about 27% on nonword reading and 24% on word reading. Ellis and Hooper (2001) compared beginning reading in English and Welsh. In parts of North Wales, English and Welsh are spoken and read side by side. In contrast to English, however, the writing system of Welsh is highly consistent. Parents choose whether they want their child to attend English or Welsh schooling. These schools serve the same geographical catchment area, are administered by the same local educational authorities, and follow similar curricula and teaching approaches. The only real difference is the language of instruction.

Ellis and Hooper (2001) reported that following roughly 2 years of reading instruction, children schooled in Welsh could read aloud approximately 61% of the written word tokens on a frequency-matched reading test, whereas children schooled in English could read only about 52%. Although this difference seems small, note that this is a consequence of using a frequency-matched test that samples a test word in decreasing steps of 10,000 word tokens. The above percentages really mean that an English-taught child could read down to the 716th word form type, whereas a Welsh-taught child could read down to the 1,821st word form type, which is well over twice as many words. A significant advantage of using frequency-matched tests is that language-specific factors such as length, imageability, morphological complexity, and so on do not need to be controlled. All factors to do with language are free to vary. Everything to do with learning opportunity is theoretically matched by controlling for frequency. This sampling procedure guarantees that the test words used in each language are highly representative of that language and is a research design that deserves to be used in more studies.

The most ambitious cross-language reading comparison to date has been conducted by the European Concerted Action on Learning Disorders as a Barrier to Human Development (reported in Seymour, Aro, & Erskine, 2003). Participating scientists[3] from 14 European Community countries developed a matched set of items of simple real words and nonwords. These items were then given to children from each country during their first year of reading instruction. This research design meant that the children varied in age but were equated for degree of reading instruction across orthography. Although method of reading instruction itself could not be equated exactly, schools were chosen so that all children (including those learning to read the more inconsistent orthographies) were experiencing phoneme-level "phonics" teaching.

The data from this study are shown in Table 2. The most striking finding from the study was that the children who were acquiring reading in orthographically consistent languages (Greek, Finnish, German, Italian, Spanish) were close to ceiling in both word and nonword reading by the middle of first grade. Danish (71% correct), Portuguese (73% correct), and French (79% correct) children showed somewhat reduced levels of recoding accuracy, which is in line with the reduced consistency of these languages. Danish is relatively inconsistent for reading (Elbro & Pallesen, 2002), whereas Portuguese and French are quite inconsistent for spelling (Defior, Martos, & Cary, 2002; Ventura, Morais, Pattamadilok, & Kolinsky, 2004; Ziegler, Jacobs, & Stone, 1996). The particularly poor performance for English-speaking children (34% correct) is in line with the *bidirectional* inconsistency of English, that is, inconsistency in reading and spelling (Ziegler, Stone, & Jacobs, 1997). These dramatic differences in reading accuracy across orthographies were mirrored by differences in reading speed. The data from all of these studies support the notion that grapheme–phoneme recoding skills are taking longer to develop in less transparent orthographies.

Table 2
Data (% Correct) From Seymour, Aro, and Erskine's (2003) Large-Scale Study of Reading Skills at the End of Grade 1 in 14 European Languages

Language	Familiar real words	Pseudowords
Greek	98	92
Finnish	98	95
German	98	94
Austrian German	97	92
Italian	95	89
Spanish	95	89
Swedish	95	88
Dutch	95	82
Icelandic	94	86
Norwegian	92	91
French	79	85
Portuguese	73	77
Danish	71	54
Scottish English	34	29

Note. From "Foundation Literacy Acquisition in European Orthographies," by P. H. K. Seymour, M. Aro, and J. M. Erskine, 2003, *British Journal of Psychology, 94,* pp. 153, 156. Copyright 2003 by the British Psychological Society. Reprinted with permission.

The Relationship Between Consistency and Granularity

It is important to be aware that inconsistency does not affect all psycholinguistic units to a similar extent. Smaller grain sizes tend to be more inconsistent than larger grain sizes, at least in English (Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). The reduced reliability of small grain sizes in relatively inconsistent orthographies may well lead children to develop recoding strategies at more than one grain size. Such development of multiple recoding strategies will necessarily take longer than developing a single recoding strategy. For example, in English it has been argued that an important recoding strategy developmentally is the rhyme analogy strategy (Goswami, 1986, 1988). Following Glushko's (1979) definition of analogies in reading, Goswami (1986, 1988) showed that English children used orthographic chunks corresponding to rhymes to read novel words from early in the acquisition process (e.g., using *beak* as a basis for reading *peak*). This raises the question of whether rhyme analogies have any role to play in reading more consistent orthographies, in which grapheme–phoneme recoding strategies alone are a perfectly efficient guide to pronunciation.

Goswami, Porpodas, and Wheelwright (1997) investigated the use of orthographic chunks corresponding to rhymes in a study comparing nonword reading in English and Greek. They gave English and Greek 7-, 8-, and 9-year-old children matched for reading ability two- and three-syllable nonwords to decode. The nonwords were either based on real words (e.g., *ticket–bicket*) or used unfamiliar orthographic patterns to represent the same phonology (*bikket*). The Greek children were close to ceiling for both types of nonword; for example, the 7-year-olds recoded 92% (bisyllables) and 85% (trisyllables) of the nonwords with familiar orthographic patterns correctly and 84% (bisyllables) and 95% (trisyllables) of the nonwords with unfamiliar orthographic patterns correctly. The English children were much more successful with the nonwords that enabled them to use rhyme analogies (e.g., ticket–bicket). Comparable figures for the English 7-year-olds were 51% (familiar bisyllables), 39% (unfamiliar bisyllables), 27% (familiar trisyllables), and 7% (unfamiliar trisyllables).

Goswami and colleagues (1998) investigated the rhyme analogy question in English and French. They gave English and French 7-,

[3] National representatives of this action were as follows: H. Wimmer, T. Reinelt (Austria); J. Alegria, J. Morais, J. Leybaert (Belgium); C. Elbro, E. Arnbak (Denmark); H. Lyytinen, P. Niemi (Finland); J.-E. Gombert, M.-T. Le Normand, L. Sprenger-Charolles, S. Valdois (France); A. Warnke, W. Schneider (Germany); C. Porpodas (Greece); V. Csepe (Hungary); H. Ragnarsdottir (Iceland); C. Cornoldi, P. Giovanardi Rossi, C. Vio, P. Tressoldi, A. Parmeggiani (Italy); C. Firman (Malta); R. Licht, A. M. B. De Groot (Netherlands); F.-E. Tonnessen (Norway); L. Castro, L. Cary (Portugal); S. Defior, F. Martos, J. Sainz, X. Angerri (Spain); S. Stromqvist, A. Olofsson (Sweden); and P. Seymour, P. Bryant, U. Goswami (United Kingdom).

8-, and 9-year-olds matched for reading age and real-word knowledge monosyllabic and bisyllabic nonwords to read. The nonwords were matched as closely as possible for mean positional bigram frequencies, and either contained familiar orthographic rhyme chunks from the real words (e.g., *dake* [cake], *loffee* [toffee]) or did not (*daik*, *loffi*). Effects of orthographic familiarity were strongest in English. For example, the English 7-year-olds recoded 56% (monosyllables) and 65% (bisyllables) of the nonwords with familiar orthographic patterns correctly, but only 36% (monosyllables) and 50% (bisyllables) of the nonwords with unfamiliar orthographic patterns correctly. Comparative performance for the French children was 83% versus 78% (monosyllables) and 81% versus 78% (bisyllables). The rhyme analogy effect was actually significant in both languages. However, the use of larger orthographic chunks in recoding clearly had a more dramatic effect on reading accuracy for the English children, improving monosyllabic recoding accuracy by 20%. In a further analysis comparing the English 9-year-olds with the French 7-year-olds (thereby equating overall recoding success with nonwords), the rhyme analogy effect was again significantly stronger for English. Nevertheless, the finding that French children as well as English children show rhyme analogy effects suggests that children learning to read inconsistent orthographies are indeed developing recoding strategies at larger grain sizes.

Further evidence that children learning to read English develop sublexical strategies at larger grain sizes comes from a study by Brown and Deavers (1999). In their study, adults and children between the ages of 6 and 10 were asked to read two sets of nonwords. Both sets had consistent orthographic rimes (large units). One set, however, contained irregular graphemes (irregular consistent nonwords, such as *dalk*). The other set contained regular graphemes (regular consistent nonwords, such as *deld*). The critical trials measured naming responses to irregular consistent nonwords, such as *dalk*. If children were using a small unit strategy (i.e., grapheme–phoneme correspondences), they should produce "regular" responses to these nonwords (e.g., /dælk/). If children were using a large unit strategy based on rhyme analogies, they should give the irregular pronunciation /dɔːk/, because this is the one that rhymes with *talk*. The results showed that both children and adults used both small and large grain sizes when reading English nonwords. Second, there was a cross-over interaction between the effects of grain size and reading skill. Brown and Deavers found a predominance of small grain size responses for the less skilled readers and a predominance of large grain size responses for the skilled readers. This has been interpreted as showing that reading acquisition begins with small units. However, it is equally possible that the less skilled readers in their study were not as efficient in supplementing grapheme–phoneme recoding strategies, which are being taught in school, with strategies based on larger grain sizes, which are not typically taught in school. The less skilled readers were not the younger children chronologically, but those with the lowest reading age (this group had a mean reading age of 8 years 8 months, whereas the skilled readers had a mean reading age of 11 years 6 months; the age range was 5–10 years).

Brown and Deavers's (1999) suggestion was that the children in their study were developing both small unit and large unit sublexical recoding strategies in parallel. The children were developing a sublexical grapheme–phoneme recoding strategy, and a sublexical rhyme analogy strategy. If English children naturally apply a mixture of small unit and large unit strategies in recoding (also termed the *flexible-unit-size hypothesis*; see Brown & Deavers, 1999), then reading accuracy for nonwords might benefit when successful recoding is possible using only one strategy at a time. If a list of nonwords contains familiar orthographic patterns at a larger grain size (large unit nonwords, such as *dake* [*cake*, *make*] and *murn* [*burn*, *turn*]), then the exclusive application of a large grain size strategy should be very successful. If, in another list, all nonwords contain only unfamiliar large unit patterns (small unit nonwords, such as *daik* and *mirn*), then recoding should be most successful if an exclusively small grain size strategy is applied. Accordingly, if both types of nonwords are mixed within a particular list (e.g., *daik*, *murn*), continual switching between small unit and large unit processing may be required, incurring a switching cost.

This scenario makes the interesting prediction that recoding accuracy for both large unit and small unit nonwords should be better if the nonwords are presented blocked into lists by grain size than if they are presented mixed together within the same list for children who are developing recoding strategies at multiple grain sizes only. In contrast, children who are learning to read an orthographically consistent language should be unaffected by this blocking manipulation. These children should preferentially use small grain size sublexical recoding strategies, and so there should be no extra advantage of blocking lists by grain size.

In a recent study manipulating these factors in English and German, Goswami, Ziegler, Dalton, and Schneider (2003) showed strong nonword blocking effects for English children but not for German children. Blocking apparently helped the English readers to focus at a single grain size, which particularly increased recoding accuracy for large unit items (e.g., with *dake*, the child can use rhyme analogies to *make*, *cake*, *bake*, etc.). German readers did not show these blocking effects despite the fact that special care was taken that, in principle, the German large unit nonwords offered the same possibilities of applying higher order correspondences as the English items (i.e., they were matched to the English nonwords in terms of number of rhyme neighbors). The absence of a blocking effect for the German readers was taken as evidence that they already relied on general and efficient processing at the small unit level. In terms of global performance, German children obtained higher accuracy scores than did English children. However, the absence of a blocking effect for the Germans was not due to ceiling effects, as was shown in post hoc analyses matching for reading level (RL) across languages.

A third reading acquisition strategy that has not been considered so far is the use of whole-word recognition (i.e., a lexical rather than sublexical strategy). Theoretically, children learning to read languages with marked degrees of inconsistency may well also supplement sublexical recoding strategies with whole-word (lexical) knowledge. For example, if English children are required to read nonwords that sound like real words—so called *pseudohomophones* (PsH)—they might show stronger influences from whole-word phonology than children reading a more consistent orthography like German. In a more consistent orthography, grapheme–phoneme recoding strategies should be sufficient for efficient phonological recoding of PsHs. However, in relatively inconsistent orthographies, the phonological familiarity of PsHs at the whole-word level might give extra support to children's nonword reading accuracy.

A study comparing the size of the PsH effect in German and English children found exactly this pattern (Goswami, Ziegler, Dalton, & Schneider, 2001). English children showed a significant advantage in naming PsHs in comparison to orthographic control nonwords (e.g., *faik* read better than *daik*), whereas German children did not. This suggests that English children were more affected by whole-word phonology when reading nonwords than were German children. German children decoded nonwords that did not sound like real words as efficiently as nonwords that did sound like real words, resulting in an absence of the PsH effect in naming. This finding is easily explained if German children rely more or less exclusively on highly efficient sublexical recoding procedures at small grain sizes (i.e., grapheme–phoneme correspondences).

In relatively inconsistent orthographies, small grain-size strategies can only approximate the production of the target for a significant number of words (e.g., "want," "here," "once"). In such situations, general vocabulary knowledge and phonological awareness skills become even more important for reading development. This is because children with larger vocabularies and stronger phonological skills are better placed to guess the partially recoded target word than children with more restricted vocabularies and weaker phonological skills. This view predicts that the relationship between vocabulary and reading development should be stronger in less consistent orthographies, where vocabulary knowledge can play an important role in bootstrapping word recognition. Comparisons of reading development in Welsh-speaking versus English-speaking children living in Wales and taught reading by the same methods provide some support for this notion (e.g., Hanley, Masterson, Spencer, & Evans, 2004; Spencer & Hanley, 2003; see also Ellis & Hooper, 2001; note that phonotactic complexity is similar in English and Welsh). For example, Hanley et al. (2004) have followed a group of Welsh-speaking children who were learning to read Welsh and a matched group of English-speaking children living in the same area of Wales who were learning to read English since they were 5 years old. Hanley and his colleagues reported that by age 11, the groups of children were comparable in tests of single-word reading in their native languages, and in nonword reading. However, the English group had previously been poorer than the Welsh group at each test point (suggesting slower reading acquisition) and also had been slower to acquire phonemic awareness. In particular, reading comprehension was significantly related to recoding in English but not in Welsh. As the two groups were comparable in recoding skills (nonword reading), this is indirect evidence that English-speaking children place greater reliance on vocabulary knowledge for accurate recoding.

The Important Role of Teaching

In alphabetic orthographies, the grain size problem is tackled by the teacher, who typically begins to teach reading from the single letter. In nonalphabetic orthographies (e.g., Chinese), the child often has no other possibility than to learn the large number of characters by rote. This can take 5 years. Interestingly, in mainland China, part of this learning problem is tackled by initial instruction in an alphabetic writing system called *pinyin*. Pinyin uses alphabetic symbols to denote the "initial" and "final" in Chinese syllables. Initials are usually single consonants (there are no consonant clusters in Chinese), and finals are usually vowels (plus a few nasals). Although pinyin is essentially phonemic, the simple syllabic structure of Chinese means that in practice pinyin is a system for coding onsets and rimes. There are only about 22 onsets and 37 rimes. All Chinese children learn pinyin for the first 8 weeks of literacy instruction before they are introduced to Chinese characters. They then receive instruction in characters with the pinyin printed above them. Onset–rime awareness in Chinese predicts pinyin acquisition, which in turn predicts Chinese character reading at later grades (Siok & Fletcher, 2001).

In alphabetic orthographies, the child is taught letter–sound correspondences, and hence learns about phonemes. As a result, phonological representations are rapidly augmented with phoneme-level information. Experience with written language changes the nature of phonological representations. In particular, it boosts phoneme awareness, which, in return, becomes the strongest predictor of successful reading, a reciprocal relationship (Perfetti, Beck, Bell, & Hughes, 1987; Rayner et al., 2001). Small grain-size teaching works well in a language with consistent letter–sound correspondences, such as Italian. However, this teaching method works less well in a language with less consistent letter–sound correspondences, such as English.

One approach to this teaching problem in English-speaking countries has been to begin the teaching of reading at younger and younger ages and to focus more and more at the phoneme level. In England itself, this approach is formalized in the *National Literacy Strategy* (Department for Education and Employment, 1998), which requires the direct teaching of reading from the age of 5 years beginning with a phoneme-based strategy. Nevertheless, English children learn to read more slowly than children from other countries, who may not begin formal instruction until the age of 7 or even 8 years. For example, Finnish children begin school at 7 and are reading with 90% accuracy by approximately the 10th week in school (e.g., Seymour et al., 2003). English children who begin school at 4 or 5 years of age are still struggling to reach 90% accuracy (e.g., for nonword recoding) by age 9 or 10 (Goswami et al., 1998).

The slower average rate of learning to read in English does not seem to occur because of variations in teaching method across different countries. Rather, it seems due to the relatively low orthographic consistency of English. This was demonstrated for example in the English–Welsh comparison described earlier (Ellis & Hooper, 2001). Converging data comes from Landerl (2000). She compared English children who were being taught to read by a "standard" mixed method of phonics and whole-word recognition with English children following a special phonics program that focused almost exclusively on letter–sound correspondences (this was a between-schools comparison conducted before the advent of the National Literacy Strategy). She reported that the first-grade English phonics group made almost as many errors on a nonword reading task (43%) as the first-grade English standard group (50%, a nonsignificant difference) compared with 12% errors for a matched German sample. At second grade, a similar pattern was found (English standard = 29% errors, English phonics = 23% errors, German children = 13% errors). It was only by third grade that the English phonics group (7% errors) performed at a rate comparable to that of the German children (14% errors) and by fourth grade that the English standard group reached a "German" level of grapheme–phoneme recoding skill (12% errors compared with 11% for the Germans).

The teaching methods characteristic of early literacy instruction in Turkish provide even more striking evidence for the relatively minor impact of different phonic teaching regimes (at least, for children with normal phonological skills). Literacy instruction in Turkish elementary schools does not capitalize particularly on the high degree of orthographic transparency. In first grade, children are given sentences to memorize. They only receive instruction on individual components such as words, syllables, or letters once the whole is memorized. Despite this large to small grain size method, children usually get their red ribbons symbolizing good decoding skills by December or January of the first school year (see Durgunoglu & Oney, 2002). In other countries with highly consistent orthographies, such as Greece and Hungary, some geographical areas have adopted the "whole language" method of initial reading instruction (the whole language method has a meaning-based rather than a code-based emphasis; reading is characterized as a psycholinguistic guessing game, bootstrapped by meaning). It is not yet clear what the effects on initial reading acquisition will be. However, judging from the data in Table 2, they are likely to be quite minor for children with good phonological skills. The effects on children with poor phonological skills are likely to be rather greater.

A different approach to the question of the optimal grain sizes for teaching has been to begin instruction with correspondences for larger units that are readily available in the phonological domain, such as rimes or syllables. As mentioned above, this approach requires the child to learn a much larger number of fairly complex letter combinations. Nevertheless, such a large unit approach to teaching appears to lead to broadly similar progress in reading English as small unit approaches. Recently, Walton and his colleagues (Walton, Bowden, Kurtz, & Angus, 2001; Walton & Walton, 2002; Walton, Walton, & Felton, 2001) compared the effectiveness of large unit and small unit approaches to the initial teaching of reading to children in Canada. In these studies, they compared the effects of teaching beginning readers to read by using a rhyme analogy strategy (*beak–peak*; see Goswami, 1986) with the effects of teaching beginners to read by using a grapheme–phoneme recoding strategy. All the children were prereaders. Reading ability was assessed following 3 months of training, and four different kinds of words were used to assess different skills (analogy, irregular patterns [*fight–sight*]; analogy, regular patterns [*bed–Ted*]; letter recoding [*bat–bet*]; and nonwords [*hib*]). Walton, Walton, and Felton (2001) found that both training groups showed broadly equal reading acquisition gains immediately following training. However, whereas the rhyme analogy group could also read new words requiring letter-recoding skills, the letter-recoding group could not read new words requiring rhyme analogy skills. When reading acquisition was followed up longitudinally, both treatment groups maintained their gains over an unseen control group, but the rhyme analogy group scored significantly above this group on all four of the reading outcome measures, whereas the letter recoding group only scored significantly above this group on two of the four outcome measures.

A third approach has been whole-word teaching (the "look and say" methods of reading in and out of vogue since the 1950s). In whole-word teaching, children are taught to recognize words as holistic units, for example via the use of flash cards (the whole word is "flashed" at the child, who must learn a pattern–sound correspondence). "Look and say" methods were shown to result in slower learning than any phonics-based method (irrespective of grain size) by the work of Chall (1967) and others in the 1970s. Exactly the same conclusion was reached recently by the National Reading Panel (2000) study of early reading in the United States. The National Reading Panel also compared the effect sizes reported for large unit versus small unit phonics teaching using a meta-analysis of relevant studies. The meta-analysis showed that the impact of early large unit teaching versus early small unit teaching was statistically indistinguishable, though significant in each case (see Ehri et al., 2001). This meta-analysis supports the experimental findings obtained by Walton and his colleagues (Walton, Bowden, et al., 2001; Walton & Walton, 2002; Walton, Walton, & Felton, 2001).

Taken together, all three approaches to teaching reading have a role to play in developing efficient word recognition, especially in relatively inconsistent orthographies (Rayner et al., 2001). For English, some words (like *choir*, *people*, *yacht*) have to be learned as distinct patterns, because they have no orthographic neighbors at all. Other words, like *light*, contain rime spellings that are common to many other words (90 words in English use the rime pattern—*ight* and are hence orthographic neighbors of *light*), and pronunciation at the rime level is consistent across the neighborhood. Still other words are quite consistent for letter–phoneme recoding (*cat*, *dog*, *pen*) and are easily decoded by traditional phonics. Nevertheless, small grain-size teaching works especially well in languages with consistent letter–sound correspondences. It is an empirical question whether children learning to read such consistent orthographies would benefit from direct teaching at complementary grain sizes; certainly such tuition does not seem to do any harm if children already have a strong phonological foundation and/or enough exposure to literacy (e.g., Durgunoglu & Oney, 1999). A related empirical question is whether there is a level of cognitive architecture for reading that develops only for inconsistent orthographies. We return to this issue in the fifth section (Part V. Alternative Theoretical Frameworks and Outstanding Critical Issues).

Phonological Development Following Literacy Tuition

As noted earlier, phoneme awareness only develops once children are taught to read and write, irrespective of the age at which reading and writing is taught, and illiterate adults tend to lack phoneme awareness skills. Children learning to read relatively consistent orthographies develop phonemic awareness more rapidly (Goswami, 2002a). This demonstrates a most intriguing aspect of learning to read and write: the effect of literacy on spoken language processes and in particular the effect on restructuring phonological representations. As Frith (1998) has commented, the acquisition of an alphabetic code is like catching a virus: "This virus infects all speech processing, as now whole word sounds are automatically broken up into sound constituents. Language is never the same again" (p. 1051). People familiar with an alphabet come to hear words as composed of the sounds represented by the letters in those words. Boucher (1994) pointed out that phonetic notation systems such as the International Phonetic Alphabet were designed by (literate) adults to investigate basic units of speech, and used alphabetic symbols to represent distinctive features. This misleadingly suggested that alphabets represented "distinctions of sound" (p. 3). Ehri and Wilce (1980) showed that literate children find it difficult to count the same number of phonemes in /ritʃ/ and /pitʃ/, because the spellings of these words contain a different number of letters (*rich* vs. *pitch)*. Similarly, a person who has never acquired an orthographic system typically finds it very difficult to delete a phoneme at the beginning or at the end of a nonword (Morais et al., 1979).

The influence of orthography on spoken word recognition and production has not only been demonstrated with children or illiterate individuals, however. The influence of orthography on spoken language processing can also be demonstrated with completely literate college students (e.g., Damian & Bowers, 2003; Frost & Katz, 1989; Frost, Repp, & Katz, 1988; Seidenberg & Tanenhaus, 1979; Taft & Hambly, 1985). For example, skilled adults find it more difficult to judge whether two words rhyme when their rimes are spelled differently (e.g., *rye–tie*) than when their rimes are spelled the same (Seidenberg & Tanenhaus, 1979). Similarly, using a phoneme detection task, Hallé, Chéreau, and Segui (2000) demonstrated that French listeners were more likely to misperceive the phoneme /p/ in /apsyrd/ than in /lapsys/. They argued that such misperceptions occurred because *absurde* is spelled with the letter *b*, whereas *lapsus* is spelled with the letter *p*. These orthographic effects clearly suggest that orthographic information can affect basic phonological processes. Nevertheless, some spoken language researchers have been reluctant to accept this notion. For example, it has been argued that this would only be the case in tasks with a strong metaphonological component (Ventura, Kolinsky, Brito-Mendes, & Morais, 2001).

In fact, orthographic effects have also been reported in tasks that do not necessarily involve metaphonological components. For example, Jakimik, Cole, and Rudnicky (1985) studied phonological priming in a lexical decision task. Facilitatory priming effects were obtained only when primes and targets shared both phonology and orthography (i.e., *napkin–nap*). No priming was obtained when targets shared only phonology (e.g., *chocolate–chalk*) or only orthography (e.g., *fighter–fig*; see also Slowiaczek, Soltano, Wieting, & Bishop, 2003). Similarly, in an auditory lexical decision task, Ziegler and Ferrand (1998) found that words with phonological rimes that could be spelled in more than one way (e.g., "cheap*"*–"cheep"; /—ip/ may be spelled *—eap* or *—eep*) produced slower correct "yes" responses and more errors than did words with phonological rimes that could be spelled in only one way (e.g., "duck"; /—uk/ may only be spelled *—uck*). Muneaux and Ziegler (2004) demonstrated orthographic effects in the off-line task of neighbor generation. Participants were asked to generate phonological neighbors for words like *wipe*. They generated words that were both orthographic and phonological neighbors, so-called *phonographic* neighbors (e.g., *ripe*), significantly more often than chance, and more often than purely phonological neighbors (e.g., *type*), suggesting that orthographic information participates in the specification of phonological neighbors in literate undergraduates. This process probably originates during development, when phonological representations become amalgamated with orthographic representations as literacy is acquired (see Part V. Alternative Theoretical Frameworks and Outstanding Critical Issues).

Part III. Developmental Dyslexia Across Different Languages

Given the importance of phonological awareness for reading acquisition, it is not surprising that deficits in the representation and use of phonological information are seen as critical in the etiology of developmental dyslexia (Catts, 1993; Snowling, 2000; Stackhouse & Wells, 1997; Stanovich & Siegel, 1994). Moreover, it is interesting that children with dyslexia from different countries show quite similar phonological deficits. Dyslexia in consistent orthographies is usually diagnosed on the basis of extremely slow and effortful phonological recoding combined with very poor spelling. Dyslexia in less consistent orthographies becomes apparent on the basis of inaccurate reading alone, although of course speed problems and spelling problems are also characteristic of the developmental phenotype. Developmental dyslexia in different languages is typically diagnosed on the basis of functional deficits in comparison with peers despite normal intellectual and educational experiences. Diagnosis in most languages follows the Organisation for Economic Co-operation and Development definition of a specific problem with reading and spelling that cannot be accounted for by low intelligence, poor educational opportunities, or obvious sensory or neurological damage. These criteria acknowledge the fact that a reading problem may also emerge because of low intellect, poor educational opportunities, or obvious sensory damage such as profound deafness. Nevertheless, to qualify as having developmental dyslexia, specific problems with reading and spelling must persist in the absence of these other causes. The Organisation for Economic Co-operation and Development definition allows the possibility that developmental dyslexia may manifest differently depending on the orthography that is being learned.

Sequential Development of Phonological Awareness in Dyslexia

To assess whether the development of phonological awareness in dyslexia follows the typical sequence (syllable → onset–rhyme → phoneme), studies of prereading children with dyslexia are required. Such studies are rather rare because dyslexia is normally only diagnosed after some years of reading instruction. As phonological representation in children with dyslexia is necessarily affected by reading experience, the skills of readers with dyslexia should not be compared only with those of children of their own age (a chronological age [CA] match design) but also to children who are reading at the same level as the readers with dyslexia (an RL match design). If the phonological or reading subskills of the children with dyslexia are inferior to those of these younger RL children, then any deficits found are likely to be fundamental rather than a simple consequence of the poorer reading experience of the children with dyslexia. Because reading experience rather rapidly causes the representation of phonemes, it is quite difficult to obtain pure information concerning syllable or onset–rime awareness in developmental dyslexia. Nevertheless, given the documented phonological difficulties of children with dyslexia, it is probable that syllable and onset–rime awareness are poor in children with dyslexia prior to tuition in reading.

The best available evidence comes from longitudinal studies of children at risk for reading difficulties (for a review, see Scarborough, 1998). For example, Schneider, Roth, and Ennemoser (2000) screened a large group of 208 at-risk German children in kindergarten prior to enrolling them in different phonological training programs designed to reduce their potential reading problems. The at-risk children were significantly poorer at rhyme production, rhyme matching, and syllable segmentation than German control kindergartners, who were not thought to be at risk. In a Dutch longitudinal study (De Jong & van der Leij, 2003), those children who were later diagnosed as having dyslexia showed poorer rhyme awareness than their control counterparts in kindergarten. It is interesting to note that at this point in time, there were no significant differences in phoneme awareness (De Jong & van der Leij, 2003), which was only weakly correlated with later reading. This is probably due to the fact that in kindergarten,

> many children who will go on to become normally achieving readers have not yet attained much, if any, appreciation of the phonological structure of oral language, making them nearly indistinguishable, in this regard, from children who will indeed encounter reading problems. (Scarborough, 1998, p. 86)

A few studies have investigated syllable and onset–rime awareness in older English-speaking children with dyslexia. Bruck (1992; RL match) and Swan and Goswami (1997; CA match) measured syllable deficits in older readers with dyslexia with syllable counting and syllable tapping tasks, respectively, and other authors have reported deficits at the onset–rime level in oddity tasks in older children with dyslexia in studies with an RL match design (e.g., Bowey, Cain, & Ryan, 1992; Bradley & Bryant, 1978). In a study on dyslexia in Korean, 11-year-olds with dyslexia scored only 37% correct in an oddity task in which the deviating element was the second phoneme of the first syllable (e.g., mo-ki, bo-ki, ko-ki, *sa-ki*) compared with 83% correct for CA controls (Kim & Davis, 2004).

As experience with written language boosts phoneme awareness, a priori, children with dyslexia would be expected to perform poorly on phoneme awareness tasks. Therefore, a more comprehensive phonemic deficit would be predicted for children with dyslexia struggling to read inconsistent orthographies than for children with dyslexia struggling to read consistent orthographies. This is because grapheme-based feedback at the phonemic level is more consistent for the latter languages, and this feedback might help children to anchor phonemes in their lexical representations.

Taking the inconsistent English orthography first, virtually all the research studies of which we are aware have found phonemic deficits in children with dyslexia compared with both RL- and CA-matched children, irrespective of the task used to assess phonemic awareness (see Goswami, 2002a, 2002b, 2002c, for more detail). Deficits at the phoneme level have been reported using the oddity task (e.g., Bowey et al., 1992), phoneme counting and phoneme deletion tasks (e.g., Bruck, 1992), and phoneme tapping and same–different judgment tasks (e.g., Swan & Goswami, 1997). For example, Bruck (1992) asked children with dyslexia aged from 8 to 15 years and RL and CA controls to count the phonemes in nonwords containing two to four phonemes such as *tisk* and *leem*. The children with dyslexia performed correctly in 47% of trials compared with 72% of trials for the RL-matched children and 77% of trials for the CA-matched children. The phoneme deficit usually found in dyslexia in English also seems to persist into adulthood. When Bruck compared adults with dyslexia with normally progressing readers in Grade 3, she found that the children were significantly better than the adults with dyslexia at both phoneme counting and phoneme deletion. Clearly, for individuals with dyslexia learning to read English, the phoneme deficit is extremely pervasive, suggesting massive disruption in those aspects of the development of phonological representation that are probably dependent on literacy.

The phoneme awareness deficit appears to be somewhat less pervasive in more consistent orthographies. For example, De Gelder and Vroomen (1991) asked 11-year-old Dutch children with dyslexia to carry out a phoneme deletion task based on nonwords (actually onset deletion; e.g., *kur* to *ur*). The children with dyslexia (61% correct) performed significantly more poorly than both RL (83% correct) and CA (99% correct) control groups. This pattern is comparable to the English data. However, when De Gelder and Vroomen gave the same task to a group of Dutch adults with dyslexia, they found no deficit at all. In fact, phonological awareness deficits in consistent orthographies can usually only be detected early in development. This is most clearly shown by longitudinal studies. In De Jong and van der Leij's (2003) longitudinal study in Dutch, children with dyslexia exhibited phonological awareness deficits at the rime level in kindergarten. These deficits were no longer seen in first grade. However, in first grade the children with dyslexia showed phonological awareness deficits at the phoneme level. These deficits were no longer seen in sixth grade (for similar findings with Austrian children with dyslexia, see Wimmer, 1996). Cross-sectional studies also have found early deficits in consistent languages. Porpodas (1999) studied Greek first graders with serious literacy difficulties and found significant differences in phonemic awareness between children with dyslexia and control children. Children with dyslexia scored 88% correct in a phoneme segmentation task compared with 100% correct for CA controls and 78% correct in a phoneme deletion task compared with 98% correct for the CA controls. As all the children were beginning readers, an RL control group could not be generated. Studies on dyslexia in Semitic languages, such as Arabic and Hebrew, have also found phonological awareness deficits in children with dyslexia (Abu-Rabia, Share, & Mansour, 2003; Share, 2003; Share & Levin, 1999). In their review of data from Hebrew, Share and Levin (1999) concluded that "phonology may well be a universal and inescapable feature of early reading and writing" (p. 107).

Development of Grapheme–Phoneme Recoding Procedures in Dyslexia

Grapheme–phoneme recoding skills are most usually measured in dyslexia with nonword reading tasks. Most studies with English children who have dyslexia report nonword reading deficits in comparison to both RL- and CA-matched controls. For more consistent orthographies, deficits are usually found in comparison to CA controls, but comparisons with RL controls may not show differences.

A comprehensive review of nonword reading in developmental dyslexia in English was provided by Rack, Snowling, and Olson (1992). Many of the studies that they reviewed found nonword reading deficits in dyslexic children as compared with RL-matched children. Error rates in reading nonwords were high, typically between 40% and 60%. The nonword reading difficulties were particularly marked when the nonwords were constructed to be dissimilar to real words (e.g., *tegwop*, *twamket*; Snowling, 1980). Rack et al. noted that English studies that did not find a nonword reading deficit in dyslexia in comparison to an RL-match control group typically used young readers (7 years) as controls and used nonwords with relatively familiar orthographic patterns (e.g., *loast* [toast]). A quantitative meta-analysis using the same database showed that the failure to obtain differences between children with dyslexia and the RL group was due to the inadequacy of the matching procedure in terms of differences in age, intelligence, and word-recognition ability (Van IJzendoorn & Bus, 1994).

There are an increasing number of studies of nonword reading by children with dyslexia in other orthographies. For example, Porpodas (1999) found that Greek first graders with dyslexia read 93% of nonwords correctly, compared with 97% for CA controls (a significant difference). Children with dyslexia in France read 75% of nonwords correctly, compared with 90% for the CA controls (Sprenger-Charolles, Colé, Lacert, & Serniclaes, 2000). Children with dyslexia in Korea read 72% of nonwords correctly compared with 100% for CA controls (Kim & Davis, 2004). On an interesting note, Korean children with dyslexia showed the strongest impairment for nonwords that required phoneme-size processing (51% correct). Dutch fourth graders with dyslexia showed marked nonword reading deficits in comparison to both CA and RL controls (Van der Leij, Van Daal, & De Jong, 2002). For Hebrew (Breznitz, 1997), third graders with dyslexia were inferior on nonword reading compared with first graders (RL controls) matched for word-recognition accuracy and reading comprehension. By fifth grade, Ben-Dror, Frost, and Bentin (1995) reported that they were unable to generate an RL control group for their reading disabled Grade 5 children because "we were unable to find children with such low [pseudoword] reading scores after first grade, whereas children in first grade could not take the morphological tests" (p. 88). For Arabic (Abu-Rabia et al., 2003), the nonword reading deficit of children with dyslexia was present in both CA and RL comparisons. Finally, a number of studies reported nonword reading deficits for German children with dyslexia. For example, in a longitudinal study, Wimmer (1996) detected difficulties in nonword reading accuracy at the beginning of the reading acquisition process. He found that 7 out of 12 children who later were diagnosed with dyslexia read less than 60% of simple nonwords like *Mana* and *Aufo* accurately, compared with an average performance of 96% correct for beginning readers who did not subsequently without dyslexia.

It may be misleading to base cross-language comparisons exclusively on accuracy data, however. This is because inconsistent orthographies provide more opportunities for reading errors to be made. Therefore, Ziegler, Perry, Ma-Wyatt, Ladner, and Schulte-Körne (2003) studied the manifestation of developmental dyslexia in English and German by focusing on reading speed. Ziegler, Perry, et al. (2003) focused on a number of theoretically important marker effects of the reading process. They reported that the similarities between orthographies were far bigger than the differences. Children with dyslexia in both England and Germany exhibited a reading speed deficit, a specific nonword reading deficit, and an extremely slow phonological recoding characterized by serial and effortful grapheme–phoneme translation. These deficits showed similar effect sizes across orthographies and persisted even with respect to RL controls (which was not the case for the accuracy data). A similar pattern has been reported by Paulesu and colleagues (2001) for adults with dyslexia. They compared reading speed for French, Italian, and English. Despite absolute differences in overall performance, when the relative effect sizes (z scores) were compared across orthographies, the nonword reading deficit of the Italian adults with dyslexia was no different from that of the French or English adults with dyslexia, despite the superior orthographic consistency of Italian.

Together, these studies suggest that individuals with dyslexia in many countries have difficulties in the establishment of basic grapheme–phoneme recoding procedures. Although grapheme–phoneme recoding might become quite accurate for such individuals in consistent alphabetic orthographies (because graphemic feedback helps with phonemic representation and because there is so little pronunciation uncertainty in these orthographies), phonological recoding speed remains extremely slow and does not differ significantly from that of individuals with dyslexia learning inconsistent orthographies (e.g., Breznitz, 1997; Paulesu et al., 2001; Wimmer, 1996; Ziegler, Perry, et al., 2003). Furthermore, these recoding difficulties do not seem to disappear in nonalphabetic orthographies, as shown by the Korean, Hebrew, and Arabic data. This suggests that the key difficulty for all readers who have dyslexia lies in the establishment of efficient processing at a small grain size. Children with phonological difficulties may never attain automaticity at these smallest grain sizes, regardless of the orthography being learned.

Are There Subtypes of Developmental Dyslexia?

Our claim that children with dyslexia in all countries show comparable phonological deficits—and comparable difficulties in phonological recoding at small grain sizes—appears in sharp contrast to the idea that it is possible to isolate subgroups of people with dyslexia, some of whom do not have problems in phonological processing. For example, it has been claimed that some people with developmental dyslexia have problems in orthographic processing without core phonological problems (*surface developmental dyslexia*; Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, & Peterson, 1996).

The subtyping argument has depended critically on the use of regression procedures. In these procedures, performance relationships between the use of lexical and sublexical phonology characteristic of normally developing children are used to derive confidence limits for assessing the same performance relationships in dyslexic populations. In the early subtyping work (Castles & Coltheart, 1993), these regression procedures typically depended on the use of CA match designs. When compared with much better readers, approximately 20% of the children with dyslexia in these studies indeed seemed to fall into two distinct subgroups, those with phonological developmental dyslexia (15% of children in Castles & Coltheart, 1993) and those with surface developmental dyslexia (19% of children in Castles & Coltheart, 1993; the rest of the children showed a mixed profile).

However, there is a methodological problem with this subtyping approach. As processing trade-offs between the reliance on lexical and sublexical phonology depend on the overall level of word recognition that the child has attained, RL-matched controls are required to discover whether the reading system itself has developed differently in developmental dyslexia. Stanovich, Siegel, and

Gottardo (1997) demonstrated this very clearly in a reanalysis of the original data presented by Castles and Coltheart (1993). Stanovich et al. showed that when RL controls rather than CA controls were used to define processing trade-offs, the surface dyslexia profile virtually disappeared. They concluded that the surface dyslexia profile arises from a milder form of the phonological deficit accompanied by exceptionally inadequate reading experience. This important finding (that people with surface developmental dyslexia disappear when RL controls are used) has now been replicated in a number of different orthographies of varying consistency (e.g., Spanish: Gonzalez, 2000; French: Sprenger-Charolles et al., 2000).

Phonological rather than orthographic deficits therefore appear to underlie developmental dyslexia in all languages so far studied. Children with dyslexia are not worse than RL children in gaining orthographic access to whole words (Grainger, Bouttevin, Truc, Bastien, & Ziegler, 2003). Rather, they are worse at computing sublexical phonology, even in languages such as Korean, German, Dutch, Hebrew, or Italian, in which the acquisition of recoding at smaller grain sizes should be facilitated by the transparency of the writing system (Kim & Davis, 2004; Van der Leij et al., 2002; Ziegler, Perry, et al., 2003).

Part IV. A Psycholinguistic Grain Size Theory of Reading

In previous sections, we have reviewed the rich cross-language database concerning phonological development, reading development, and dyslexia. In this section, we attempt to integrate these data into a theoretical framework for describing reading acquisition, skilled reading, and dyslexia in different languages. According to our psycholinguistic grain size theory, understanding phonological development is important for understanding reading development, and understanding reading development is important for understanding skilled reading. The development of reading is grounded in phonological processing. Because languages vary in phonological structure and in the consistency with which that phonology is represented in the orthography, there will be developmental differences in the grain size of lexical representations and reading strategies across orthographies. Accordingly, the lexical organization and processing strategies that are characteristic of skilled reading in different orthographies may be affected by differing developmental constraints.

Phonological Development Prior to Reading

Phonological structure in different languages and children's phonological knowledge of those structures needs to be accorded a central role if reading and reading development is to be fully understood. The data reviewed above (see Part I. Phonological Development Prior to Reading Across Different Languages) suggest that the most accessible phonological units for the truly beginning reader are the larger units (e.g., whole words, syllables, onsets, onset–vowel or body units, rimes). Psycholinguistic grain size theory proposes that phonological awareness of syllabic and intrasyllabic structure is an emergent property of phonological similarity at the lexical level (see also Metsala & Walley, 1998; Storkel, 2002). Redundancies within neighborhoods of similar-sounding words highlight invariant units that are shared across all words in that neighborhood. As discussed above, depending on the nature of phonological similarity relations within a language, the rime emerges as a salient grain size in some languages (e.g., English, German, Dutch, French), whereas the body or onset–vowel unit does so in others (e.g., Korean).

Early in language development, there may be minimal grouping of lexical forms by phonological similarity, even though relatively fine-grained phonological detail (phonetic features) may be represented (Swingley & Aslin, 2000, 2002). As vocabulary grows, however, lexical representations of similar sounding "families" emerge (e.g., dense rime neighborhoods) and become integrated with this more fine-grained phonological information. Our view is that structural regularities present in the lexicon of spoken word forms (such as neighborhood characteristics) may form the basis of incidental learning about phonology, just as statistical regularities present in sequences of syllables (phonotactic and transitional probabilities) are thought to form the basis of word segmentation and learning (e.g., Saffran et al., 1997). Whereas the latter appears to rely on "chunking" of the speech stream according to transitional and phonotactic probabilities (Saffran, 2001; Saffran et al., 1997), the former may require the inspection of memory traces for discrete representations and the projection of generalizations that go beyond the surface forms of these items in memory. According to this account, lexical restructuring is not a process whereby coarser representations are replaced by increasingly segmental representations. Rather, it is one in which representations are augmented with phonological detail at both large and small grain size levels. Thus, word representations are thought to change in terms of specificity and redundancy (Perfetti, 1992).

This similarity-based view of the lexical restructuring process postulates that words in dense neighborhoods will experience more pressure toward restructuring than words in sparse neighborhoods. Furthermore, because reading acquisition itself affects phonological development (the reciprocal relationship), grain size theory predicts that orthographic neighborhood similarity will participate in the phonological restructuring process (see Muneaux & Ziegler, 2004). This prediction is consistent with a large number of studies showing orthographic influences on phonological awareness (e.g., Ben-Dror et al., 1995; Ehri & Wilce, 1980; Ventura et al., 2001). As reading and spelling develop, phonological awareness tasks are increasingly subject to orthographic influences. Even adults have difficulty in deleting the fourth phoneme in "faxed" (to give "fact"), presumably because this phoneme is not represented by a letter. The same adults can easily delete the fourth phoneme in "stable," which is represented by a letter (leaving "stale"; 86% of adults succeeded with "stable" compared with 6% with "faxed"; see Scholes, 1998). However, it is important to realize that such demonstrations do not undermine the view that prior to reading, phonological sensitivity is a causal predictor of reading progress (see Castles, Holmes, Neath, & Kinoshita, 2003, for such an argument). Castles et al.'s (2003) actual finding was that phonemic awareness for orthographically transparent words (e.g., /m/ in *dome*) was better than for orthographically opaque words (e.g., /m/ in *comb*). The assumption that orthographic similarity participates in phonological restructuring readily explains why this was so. The orthographic similarity is far greater for *dome* (*home*, *Rome*, etc.) than for *comb*, and so according to grain size theory, this affects the phonological restructuring of individual word representations.

Given that access to phonemes is not readily available prior to reading, all major theories of reading acquisition argue that gaining access to phoneme-size units is a crucial step for the beginning reader of an alphabetic language (Ehri, 1992; I. Y. Liberman et al., 1974; Perfetti, 1992). Such access is necessary for the establishment of complete mappings between orthography and phonology, even in terms of the development of a sight word vocabulary (Ehri, 1999). Psycholinguistic grain size theory predicts that this problem is attenuated in languages like Italian and Spanish because of redundancy at smaller grain sizes. For example, languages like Italian have many simple (CV) syllables, for which onset–rime segmentation is equivalent to phonemic segmentation (e.g., *casa*, *mama*: here onset–rime units and phonemes are the same). Phoneme-sized units are in effect represented for many words via onset–rime representation, ready to be discovered as letters are learned. The discovery of phoneme-size units is more difficult in languages with a more complex phonological structure. For languages like English and German, which have many complex syllables ending in codas (e.g., *film*, *Film*, *hand*, *Hand*), onset–rime segmentation does not typically correspond to phonemic segmentation. For these languages, the normally developing child who has already organized his or her phonological lexicon in terms of onsets and rimes is less well-placed to acquire alphabetic literacy. However, as we have shown in Part III, this child still has an advantage over the child whose lexicon of spoken forms does not efficiently represent phonological information (the child with developmental dyslexia).

Reading Development

According to psycholinguistic grain size theory, a major cause of the early difficulty of reading acquisition is that phonology and orthography initially favor different grain sizes. Phonology favors larger grain sizes, whereas orthography favors small grain sizes (letters). Depending on the simplicity of the phonological structure of a given language or the degree of direct training in phoneme awareness provided, as the child learns letters the child discovers and isolates phonemes. This in turn augments the child's understanding that letters or letter clusters (graphemes) represent phonemes. The relationship between reading ability and phoneme awareness is necessarily reciprocal. That is, children begin learning about phonemes via letters, but a certain level of phonemic awareness may be necessary for grasping the alphabetic principle per se. As the learning of grapheme–phoneme mappings progresses, graphemic knowledge in turn promotes the development and refinement of phonemic awareness. This reciprocal relation predicts that the consistency of grapheme–phoneme relations, both in terms of pronunciation and spelling, will have an impact on learning to read.

Indeed, as reviewed in Parts I and II, phonological structure and phonological similarity do predict how easily a child will become aware of salient phonological units, and the consistency of the orthography does predict which writing systems are learned fastest and most easily. As demonstrated by the large-scale European Community study (Seymour et al., 2003), reading accuracy in orthographically consistent languages (Greek, Finnish, German, Italian, Spanish) is close to ceiling for both word and nonword reading by the middle of first grade. Reading accuracy in languages that have inconsistencies either in reading (e.g., Danish) or in spelling (e.g., French, Portuguese) is intermediate (about 70%). Reading in languages that have inconsistencies in both reading and spelling (e.g., English) shows the lowest accuracy (about 40%).

According to psycholinguistic grain size theory, both grain size and consistency are crucial for explaining these striking differences in the ease of acquisition. Young learners of relatively consistent languages can focus exclusively at the small psycholinguistic grain size of the phoneme without making many reading errors. Consistent feedback received in terms of achieving correct pronunciations reinforces the acquisition process further. When small grain-size correspondences are inconsistent (e.g., English) or not available (e.g., Chinese), beginning readers have to learn additional correspondences for larger orthographic units, such as syllables, rimes, or whole words. There are many more orthographic units to learn when the grain size is large than when the grain size is small. For instance, to decode the most frequent 3,000 monosyllabic English words at the level of the rime, a child needs to learn mappings between approximately 600 different orthographic patterns and 400 phonological rimes.

The grain size problem leads to an even greater learning problem for a beginning reader of Chinese. The character writing system represents morphosyllabic but not phoneme-size information (Perfetti & Tan, 1998). A Chinese child has to learn by rote the 3,000 visually different characters that make up the syllable and morpheme stock of the language, a process that takes a minimum of 3 years, but usually takes longer (Gleitman, 1985). This process of rote learning corresponds to literacy teaching in Hong Kong (Huang & Hanley, 1994; Siok & Fletcher, 2001). However, in Taiwan, children spend the first 10 weeks of schooling learning a phonetic script with subsyllabic segments (Zhu-Yin-Fu-Hao) to reduce the enormous learning problem. Similarly, children in mainland China learn the alphabetic pinyin script for 8 weeks before they are introduced to Chinese characters.

Thus, psycholinguistic grain size theory suggests that the dramatic differences in reading accuracy and reading speed found across orthographies reflect fundamental differences in the nature of the phonological recoding and reading strategies that are developing in response to the orthography. For example, in alphabetic languages, children who are learning to read more orthographically consistent languages, such as Greek, German, Spanish, or Italian, rely heavily on grapheme–phoneme recoding strategies because grapheme–phoneme correspondences are relatively consistent. Children who are learning to read less orthographically consistent languages, such as English, cannot use smaller grain sizes as easily because inconsistency is much higher for smaller grapheme units than for larger units like rimes (Treiman et al., 1995). As a consequence, English-speaking children need to use a variety of recoding strategies, supplementing grapheme–phoneme conversion strategies with the recognition of letter patterns for rimes and attempts at whole-word recognition. Inconsistent orthographies like English appear to push readers into developing both small unit and large unit recoding strategies in parallel. English children show much stronger influences from whole-word phonology when reading PsHs (Goswami et al., 2001), they show stronger switching costs when words cannot be decoded using one grain size only (Goswami et al., 2003), and they show evidence for the adaptive use of large unit and small unit strategies in response to task demands (Brown & Deavers, 1999). Given that English seems to lie at the extreme end of the consistency continuum with regard to orthography–phonology relationships, it might even be the case that some of the most sophisticated processing architecture (e.g., two separate routes to pronunciation in the skilled reading system) may in fact only develop for English. This is a particularly striking idea given the large number of studies of reading conducted in English and the influence that theoretical models of reading in English have had on models in other languages.

However, it is important to note that the development of recoding strategies at multiple grain sizes does not hold back English children in terms of developing grapheme–phoneme recoding strategies. Rather, the development of multiple grain size strategies is an efficient response to the orthography. Given the fundamental role of phonology in skilled reading and reading acquisition in all languages studied so far (Bosman & de Groot, 1996; Bruck et al., 1997; McBride-Chang & Kail, 2002; Perfetti, Zhang, & Berent, 1992; Share & Levin, 1999; Siok & Fletcher, 2001; Ziegler, Tan, Perry, & Montant, 2000), the difference between languages does not seem to lie in the overall "amount" of phonological versus orthographic activation that is needed for reading aloud. Learning any writing system requires an efficient mapping to phonology. All beginning readers need to develop efficient phonological recoding strategies, but the strategies themselves may need to differ in terms of grain size to meet the requirements of the orthography that is being read.

Finally, it is important to state that it would be misleading to think of psycholinguistic grain sizes as being mutually exclusive. For instance, grain size theory does not postulate a separate orthographic rime layer between letters and words. As we have shown above, grain sizes do not emerge at a given point in development across the entire lexicon. Rather, they are word and neighborhood specific, a view that is consistent with nonstage incremental theories (Harm & Seidenberg, 1999; Perfetti, 1992; Share, 1995). Salient units of different grain size emerge in response to the following different kinds of pressures: (a) functional pressure toward smaller units that are orthographically less complex, (b) linguistic pressure toward bigger units that are phonologically more accessible, and (c) statistical pressure toward units that are more consistent than others. Such multiple pressures predict that one should naturally find evidence for both small and large grain sizes in reading depending on task constraints, stimuli, the method of reading instruction, and the language. This view is incompatible with attempts to reduce theories of development to simplistic "small units first" or "small units are best" approaches (e.g., Duncan et al., 1997; Hulme, 2002).

Developmental Dyslexia

In most theories of developmental dyslexia, deficits in phonological processing are seen as central (e.g., Snowling, 2000). Psycholinguistic grain size theory is no exception. Some theories, however, predict that dyslexia is reduced in consistent languages like German and Italian (e.g., Wydell & Butterworth, 1999). In their hypothesis of granularity and transparency, Wydell and Butterworth (1999) recognized that grain size (granularity) and orthographic consistency (transparency) are the critical theoretical issues. However, they argued that (a) transparent (i.e., consistent) orthographies will show low incidences of developmental phonological dyslexia because print-to-sound translation is one-to-one and (b) orthographies that operate at very coarse grain sizes (i.e., logographies and syllabaries) will also show low incidences of developmental phonological dyslexia because subsyllabic processing will not be required for reading. Psycholinguistic grain size theory, in contrast, does not predict that orthographic consistency reduces developmental dyslexia in any simple way. There is an important role for development in developmental disorders (see Goswami, 2003; Thomas & Karmiloff-Smith, 2002). If it is accepted that reading is founded in phonology, then children with dyslexia will experience difficulties in acquiring even consistent orthographies. This is because of their reduced phonological sensitivity.

We predict instead that (a) the incidence of developmental dyslexia will be very similar across consistent and inconsistent orthographies but that its manifestation might differ with orthographic consistency (as indeed has been documented in this review) and (b) the incidence of developmental phonological dyslexia will not be reduced in any simple way by coarse grain sizes, as phonological awareness of subsyllabic units may still be necessary for the acquisition of the characters or symbols used in coarse grain-size orthographies (see Siok & Fletcher, 2001). Theoretically, Japanese Kana (a syllabary) may be an example of a world orthography for which subsyllabic processing is not required to learn to read (although, typically, Japanese children also learn to read approximately 1,000 Kanji units). Even with Japanese Kana, however, a decreased manifestation of developmental phonological dyslexia does not seem to be found. Recent developmental work in Japanese (so far not published in English) suggests that individuals with developmental dyslexia show the same phonological problems as children with dyslexia in all the other world languages studied to date, displaying difficulties in tasks like syllable deletion, syllable reversal, nonword repetition and rapid automatized naming (e.g., Kobayashi, Kato, Haynes, Macaruso, & Hook, 2003). Wydell and Butterworth (1999) reported a case study of a bilingual teenage boy who was apparently dyslexic in English but not in Japanese, as he read both Kana and Kanji characters well. However, it is notable that they did not measure his Japanese nonword-reading abilities, particularly in terms of timed performance. If they had done so, it is likely that he would have displayed clear deficits in reading Japanese as well as in reading English.

In our view, atypical development in reading can arise either from variations in the initial constraints on learning (e.g., a phonological deficit, being blind) or from variations in the training environment (e.g., impoverished exposure to print, being exposed to two different orthographies at once) or from an interaction between the two. According to psycholinguistic grain size theory, children with a phonological deficit are at risk of dyslexia in all languages, and children with milder phonological deficits who have particularly inadequate exposure to print will also be at risk of dyslexia in most languages. The critical factor for predicting how dyslexia will manifest in a particular language will be the transparency of the orthography, but other relationships between orthography and phonology may be important as well. Most research in alphabetic languages has focused on links between orthography and phonology at the level of recoding a visual symbol into a sound pattern such as a syllable or a set of phonetic features. However, some orthographies may require well-specified phonological representations for accessing suprasyllabic aspects of spoken language that are important for comprehension, such as tone or stress. Hence, impaired phonological skills may hamper reading development for reasons additional to the need to operate efficiently at small grain sizes.

Part V. Alternative Theoretical Frameworks and Outstanding Critical Issues

Cognitive psychology and developmental psychology have often been uncomfortable bedfellows (Bishop, 1997). This has certainly been true in the domain of reading, where most theories of skilled performance have developed independently of the extensive literature on phonological and reading development (for a notable exception, see Harm & Seidenberg, 1999). By making an explicit connection between phonological processing prior to literacy and patterns of reading development in different orthographies, psycholinguistic grain size theory offers a unified framework for understanding reading and reading development across different orthographies. Grain size theory is difficult to compare with other theories because other theories tend to focus on a single aspect of development or performance, such as phonological development or reading development or skilled reading. Nevertheless, in this section, we try to compare psycholinguistic grain size theory with other theoretical approaches. In doing so, we also highlight important issues that require further research and discussion.

Theories of Phonological Development

With regard to phonological development, two main theoretical positions have been proposed. The *modular* view assumes that phonemic structure is present in children's word representations from birth but that they are unaware of this structure because it is represented within a dedicated phonetic module (A. M. Liberman, 1970). This view arose from traditional theories of speech perception and processing, in which the phoneme was assumed to be the basic unit. According to this view, children learn explicitly about the phonemic structure that is already present implicitly in their lexical representations via being taught to read.

The alternative *holistic* view suggests that children add phonological information to lexical representations during development so that they are able to differentiate among the increasing numbers of phonologically similar items in their spoken vocabularies (e.g., Metsala & Walley, 1998). On this view, phonological awareness, so critical for reading acquisition, is an emergent property of vocabulary growth: "Developmental changes in the nature of basic speech representations play a crucial role in the emergence of phoneme awareness and early reading ability" (Garlock, Walley, & Metsala, 2001, p. 469). This represents a critical difference from the modular view, as the latter does not accord vocabulary growth a role in the development of phonemic awareness.

Grain size theory shares certain assumptions with the holistic view, except that it does not argue that vocabulary growth yields the phoneme prior to literacy. In our view, awareness of sounds at the smallest grain size (phonemes) does not develop automatically as children get older. The discovery of the phoneme as a psycholinguistic unit depends largely on direct instruction in reading and spelling (e.g., I. Y. Liberman et al., 1974) and on the receipt of targeted training at the phonemic level (e.g., Byrne & Fielding-Barnsley, 1995; Morais, Content, Bertelson, Cary, & Kolinsky, 1988). The need for direct training may of course be reduced in languages whose phonological or morphological structure facilitates the emergence of phonemes (e.g., Italian, Turkish). There is also a third logical possibility distinct from the holistic and modular views: Phonological awareness may be an emergent property of vocabulary growth for large units within words (i.e., syllables, onsets, rhymes), whereas the awareness of small units may require direct instruction. Learning an alphabetic writing system is the most usual form of such instruction and induces the representation of phonemic structure in the phonological lexicon (see also Rayner et al., 2001). This third logical possibility is that adopted by psycholinguistic grain size theory.

Theories of Reading Development

Most developmental researchers would agree with the spirit of Ehri's (1992) amalgamation theory of reading development. According to Ehri's (1992) theory, an important part of reading acquisition is practice in reading specific words by phonologically recoding them. This process results in the creation of access routes for these words into lexical memory. Young readers build these access routes by using their knowledge of grapheme–phoneme correspondences to amalgamate particular letters in the spellings of words to particular phonemes in the pronunciations of the words. The letters are processed as visual symbols for the phonemes and the sequence of letters is retained in memory as an alphabetic, phonological representation of a particular word. Similarly, Perfetti (1992) conceptualized the amalgamation process as one in which "a fully specified orthographic representation is bonded to the phonemic representation" (p. 160)—much as in chemical bonding (see also Van Orden & Goldinger, 1994).

Grain size theory differs from Ehri's (1992) amalgamation theory largely in its special emphasis on the development and use of different grain sizes and recoding strategies across orthographies. That is, we claim that phonological structure, phonological and orthographic neighborhood characteristics, and the transparency of spelling–sound mappings act together to determine the units and mappings that play a role in the amalgamation process in different orthographies. As we have shown, learning to read a consistent orthography relies to a great extent on grapheme–phoneme size mappings, and orthographic consistency facilitates rapid phonemic development, a reciprocal relationship. More inconsistent orthographies seem to force the reading system into developing multiple grain size mappings, and so learning to read inconsistent orthographies depends on greater developmental flexibility and the development of extracognitive architecture (Goswami et al., 2003). In consistent orthographies, the development of multiple grain size mappings may be unnecessary and may even take longer than utilizing simple grapheme–phoneme mappings.

How important are considerations of granularity for understanding reading development in different languages? One test is to see whether existing connectionist learning models derived for English can simulate reading development in consistent and inconsistent orthographies without taking differences in grain size, reading strategies, or teaching methods into account. To explore this question, Hutzler, Ziegler, Perry, Wimmer, and Zorzi (2004) compared the performance of two major connectionist reading models in two languages, the triangle model (Plaut, McClelland, Seidenberg, & Patterson, 1996) and the two-layer associative model (Zorzi, Houghton, & Butterworth, 1998a, 1998b). These models were trained on a comparable database of German and English words and were tested on an identical set of German and English nonwords at different stages during the process of learning to read. The authors found that both models showed an overall advantage for the more consistent orthography (i.e., an advantage for German over English). However, the networks exhibited no cross-language differences during initial learning phases. Rather, there were increasingly large differences during later learning phases. This is the opposite of the empirical pattern (Frith et al., 1998; Goswami et al., 2001), in which German beginning readers outperform English beginning readers but differences are attenuating by a reading age of around 10 years.

It seems that the models fail to capture the cross-language learning rate effect because they deal only with the implicit aspects of the learning process. Both models are presented with words that are fully segmented into letters, and they learn about their correspondences with a phonology that is already fully specified in terms of phonemes. In essence, the connection between the two domains is the only thing that is learned. The models behave as if they already contained fully specified orthographic and phonological representations prior to reading. Also, the learning process itself is modeled as beyond the control of the reader or the teacher—it is implicit. In real life, however, learning to read starts out with explicit processes, such as the explicit teaching of small grain-size correspondences. It is these explicit processes and their potential interactions with the more implicit aspects of lexical processing that are missing from the models.

As we have demonstrated throughout this review, a key feature of learning to read consistent orthographies is the reliability of correspondences at small grain sizes. This boosts the acquisition of phonological recoding and phonemic awareness, especially during the early phases of reading acquisition, and seems to have long-lasting effects on the skilled reading system (see *Theories of Skilled Reading*). Given that current connectionist learning models are not sufficiently sensitive to the fact that literacy acquisition in consistent orthographies starts out with explicit teaching of small unit correspondences, the failure of these models to fully capture the empirical data is not surprising. In fact, when Hutzler et al. (2004) pretrained Zorzi et al.'s (1998a, 1998b) two-layer associative model on simple grapheme–phoneme correspondences prior to the word learning process, thus imitating what happens during phonics teaching, the model accurately predicted the cross-language learning-rate effect.

If these points are accepted, then a way forward is obviously to develop new connectionist models that can encompass the critical developmental processes. Connectionist models are essentially learning systems. The ways in which they develop internal representations depend on the constraints on learning built in by the modeler, as well as on the particular training environments that the models are exposed to (Thomas & Karmiloff-Smith, 2002). We have argued that how the child learns to read depends on preexisting constraints developed while he or she acquires spoken language (namely, the available levels of phonological awareness and the phonological competence of the child) and the training environment to which the child is exposed (namely, the orthography and how it is taught). Our basic claim is that if a child with good phonological awareness is exposed to an inconsistent orthography, the kinds of internal representations that will develop to support reading (the psycholinguistic units) will differ from the kinds of internal representations that will develop if the same child is exposed to a consistent orthography. This analysis suggests that new connectionist models need to be developed that better reflect the development of phonological representations prior to reading, the development of these representations through reading, and the emergence of orthographic representations as a result of learning. These new models need to be equipped to capture the different training environments provided by different orthographies and different methods of instruction (see Hutzler et al., 2004).

Theories of Skilled Reading

Psycholinguistic grain size theory clearly shares many features with the orthographic depth hypothesis (ODH; Frost et al., 1987; Katz & Feldman, 1983). The ODH was based on the dual route model of reading (for a recent review, see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The ODH does not postulate that different psycholinguistic units develop in response to differences in orthography. Rather, the ODH suggests that readers adapt their reliance on the two pathways assumed basic for reading (lexical and nonlexical), depending on the demands of the orthography. In a consistent orthography, readers rely more on the phonological, or nonlexical, pathway because the mapping between letters and sounds is relatively direct and unambiguous. In an inconsistent orthography, readers rely less on the phonological pathway and to a greater extent on the lexical, or orthographic, pathway. They shift the weight accorded to the two pathways because of the less systematic mappings between spelling and sound in inconsistent orthographies.

One key prediction of the ODH is that phonological effects should be reduced in a relatively inconsistent orthography such as English. However, a large number of studies found strong phonological effects in English in a variety of paradigms (e.g., Perfetti & Bell, 1991; Rayner, Sereno, Lesch, & Pollatsek, 1995; Van Orden, 1987; Ziegler, Van Orden, & Jacobs, 1997; for a review see Frost, 1998). Although Katz and Frost (1992) correctly pointed out that such data only challenge the strong version of the ODH, according to which people who read deep orthographies never use phonological information, such studies still show that phonological processes play a role in reading both consistent and inconsistent orthographies.

Moreover, some of the developmental cross-language data reviewed above are difficult to account for in terms of the ODH. For example, in the study carried out by Goswami et al. (2001), German readers showed no PsH advantage in naming whereas English readers did. This, however, did not mean that German readers relied less on the phonological pathway. In a subsequent lexical decision experiment using the same items as the naming experiment, German readers showed stronger phonological interference effects than English readers (they were twice as likely to think that nonwords like "Bluume" [flower; *Blume*] were real words). This suggests that the efficient use of small grain sizes in German makes whole-word phonology effects in naming more difficult to detect. It does not mean that German readers rely less on phonological processes. Indeed, some of the original advocates of the ODH have come to the following conclusion:

> We no longer believe that the difference [between shallow and deep orthographies] is one of whether or not phonology is routinely in-

> volved in visual word recognition . . . We now think that the difference is merely methodological, a matter of the greater simplicity with which one can contrive an experimental demonstration of phonological involvement. (G. Lukatela & Turvey, 1998, p. 1069)

Another obviously relevant set of models for describing the data discussed in this review are the rich and elegant computational models of reading that have been developed by researchers in skilled reading. With the exception of Harm and Seidenberg's (1999) parallel distributed model, however, models such as the dual route cascaded model (Coltheart et al., 2001), the multiple read-out model (Grainger & Jacobs, 1996), or the triangle model (Plaut et al., 1996) have not tackled the question of development. Their focus has been, quite naturally, on the skilled reading system. To the extent that they are not sensitive to developmental or phonological constraints prior to reading, it is likely that they will find it difficult to simulate some of the footprints that development leaves on skilled reading.

One example of a developmental footprint is Perry and Ziegler's (2000) demonstration that words that were more difficult to spell in childhood were more difficult to read in adulthood. Having excluded a number of potential explanations of this effect via a tight experimental design, they suggested that phonological constraints and linguistic difficulties during reading and spelling development left a measurable effect on skilled reading. It is difficult to see how a model that is not sensitive to linguistic and phonological constraints during development could account for such data. In fact, Perry and Ziegler (2000) ran simulations with the dual route cascaded model and the multiple read-out model and showed that these models did not predict the empirical effects found behaviorally.

Another example of a developmental footprint is the demonstration that skilled German readers exhibit a preference for small unit processing whereas skilled English readers exhibit a preference for large unit processing (Ziegler, Perry, Jacobs, & Braun, 2001). In this study, identical items were used in both languages (e.g., *zoo–Zoo*, *sand–Sand*, *ball–Ball*). Notice that these are not loan words in the respective languages, but genuine German and English words. Orthographic rime or "body N" effects were used as a marker for large unit processing, and word-length effects as a marker for small unit processing. It was expected that German readers would show stronger length effects than English readers on the same items whereas English readers would show stronger rime or body N effects than German readers. This is exactly what was found for both word and nonword reading.[4]

Ziegler and colleagues (2001) argued that this preference must have been developmentally established, as similar patterns are found in children (see Part II. Developmental Dyslexia Across Different Languages). On an interesting note, recent simulation work (Perry & Ziegler, 2002) showed that a connectionist learning model (i.e., the dual process model by Zorzi et al., 1998a, 1998b) could not predict the behavioral patterns found. This was because the greater consistency of the German orthography actually drove the German model to process larger units rather than smaller units. The model adopted the processing pattern opposite to the one observed by Ziegler et al. (2001) for the German adults. At the same time, the dual route cascaded model, which can predict the length effect found in German (i.e., the small grain size effect), could not predict the greater reliance of English adults on orthographic rime units. This is probably because neither phonological nor orthographic processing is sensitive to rime size units in this model (see Ziegler & Perry, 1998).

One final example of a possible developmental footprint comes from the accumulating literature on orthographic effects in spoken word recognition (Hallé et al., 2000; Jakimik et al., 1985; Seidenberg & Tanenhaus, 1979). In search of a theoretical explanation for these effects, it had been argued that orthographic effects on phonological processing would only be found in tasks with a strong metaphonological component, such as rhyme judgment, phoneme detection or phoneme blending (Ventura et al., 2001). However, as summarized earlier, orthographic effects have now been reported in tasks that do not necessarily involve metaphonological components, such as lexical decision (Slowiaczek et al., 2003; Ziegler & Ferrand, 1998; Ziegler, Muneaux, & Grainger, 2003). These orthographic effects seem to disappear in nonlexical tasks, such as shadowing (Ventura et al., 2004; Ziegler, Ferrand, & Montant, 2004). Psycholinguistic grain size theory can easily explain the presence of these effects in lexical decision and their absence in shadowing by assuming that orthographic information plays a crucial role during the restructuring of lexical representations in childhood. As this restructuring will have a long-lasting impact on the specificity and quality of phonological representations, grain size theory offers a parsimonious explanation for the existence of orthographic effects in adult auditory word recognition in lexical tasks but not necessarily in nonlexical tasks.

In summary, in contrast to many other approaches to explaining skilled reading, the grain size theory conceptualizes reading as being continuous from childhood to adulthood. Rather than assuming that development is over by (say) age 10, we suggest that developmental aspects of lexical structuring and processing will continue to affect the long-term organization and dynamics of the skilled adult reading system. This is an important idea because, logically, it could be the case that early developmental constraints become superfluous, or that the grain size of phonological representations reaches a ceiling at a certain age. In these scenarios, early developmental patterns would have no effect on later skilled reading. Contrary to this possibility, we argue that early developmental processes are the basic building blocks for later skilled reading. The lexical organization and processing strategies characteristic of skilled reading are necessarily affected by developmental constraints. Further, these developmental constraints will vary with orthography.

Conclusion

Psycholinguistic grain size theory is only a first sketch of the kinds of parameters that need to be taken into account to understand the complex relation between phonological development, reading acquisition, skilled reading, and developmental dyslexia. It is obvious that more research, especially more systematic cross-language research involving both children and adults, is needed to fill in the gaps and to formulate more complex predictions. Psy-

[4] Ellis and Hooper (2001) replicated this effect. Readers of the highly consistent Welsh orthography showed stronger length effects than did English readers, whereas English readers showed stronger large unit effects than the Welsh readers.

cholinguistic grain size theory makes it clear that in the future researchers need to integrate domains that have traditionally worked in isolation. Classically, researchers have designed their experiments as though visual word recognition was unaffected by auditory word recognition, as though reading development was unaffected by language development, and as though skilled reading was unaffected by phonological development. We suggest that future research needs to construct critical manipulations that can track the mutual dependencies across these domains at different points in development and across different language environments. For example, studies could specify the development of phonological structures in different languages prior to reading and then study how these structures are modified with reading development and different methods of reading tuition. Studies could explore how learning to read and to spell is constrained by phonological and linguistic factors that are specific to each language, such as neighborhood distributions, consistency and grain size differences, and even stress patterning and other suprasegmental parameters that affect comprehension (which are explicitly marked in certain orthographies). Behavioral, simulation, and brain imaging research could study the potential trade-offs between structural-residual and online competition effects. In our view, such systematic comparisons across languages are bound to yield rich rewards.

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