ORTHOGRAPHIC LEARNING, PHONOLOGICAL RECODING, AND SELF-TEACHING

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I. Introduction

A. PROLOGUE

First, I would like to ask the reader to read the following short passage. Please read at your own natural reading pace—much as you would read a light novel.

> In the middle of Australia is the hottest town in the world. This town is called Sloak and it's right in the middle of the desert. In Sloak, the temperature can reach 60 degrees. It's so hot that even the flies drop dead and the rubber tires on the cars start to melt. You can even fry an egg on the roof of your car.

Advances in Child Development and Behavior
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The houses in Sloak are under the ground, far away from the heat of the sun. The people also dig for gold deep under the ground. In Sloak, they drink lots of beer to stay cool. They drink beer in the morning, in the afternoon, and in the evening. The beer in Sloak is very strong. If you're not used to drinking beer you'd better watch out!

Would you like to live in Sloak?

It will immediately strike the reader that this text is aimed not at beer-lovers but at young children—actually second graders. And those familiar with the Australian "outback" will appreciate that this imaginary town is not entirely fictitious. Now that I've managed to filibuster for a sentence or two, we can get back to the story of orthographic learning, but first, one other small request. *Without going back to the text*, look carefully at the following two spellings—*SLOAK/SLOKE*. Which do you think was the name of the town in the story? Because both are what we call "pseudo-words"—invented or possible words that do not actually exist, no prior knowledge is available to help out. And because the two spellings sound exactly the same, in weighing up the two alternatives you have only your memory to rely upon for the specific spelling seen a few moments ago. So, how did you do? It turns out that skilled adult readers and young inexperienced readers alike demonstrate a surprisingly strong preference for the original spelling. It might be objected, however, that this spelling somehow looks "right" or more "wordlike," and would have been favored even if it had not appeared in the passage. But even when the alternative spelling *Sloke* replaces *Sloak* throughout the passage, the advantage for this spelling is just as strong (see, e.g., Share, 1999). In any case, these pre-existing "orthographic preferences" can be checked independently to ensure that both spellings look equally plausible or "wordlike" for a particular group of readers.

The evidence reviewed in this chapter shows that not only are able readers remarkably adept at distinguishing the original spelling from its so-called "homophonic foil," but this newly acquired knowledge is manifest in a variety of tasks including regular pen-and-paper spelling, and also naming times—the original spelling is consistently pronounced more quickly and with fewer errors than the alternate unseen spelling. This learning also seems to occur surprisingly rapidly; there were only six occurrences of the "target" word (*Sloak*) in the passage presented previously, but even a single exposure may be sufficient to get the learning process underway (Share, 2004).

No less remarkable is the durability of this learning. The data collected by a number of different researchers working in a variety of languages (not just English) clearly show that if the spelling choice task you just performed had been delayed until after you had finished reading this chapter—the choices would be no less impressive. In fact, in another week (or even another month!) you would probably still be able to recognize the original spelling—not necessarily with unwavering certainty, but at levels well beyond the 50% chance level. Summing up, a growing number of studies now indicate that this process of picking up these visual (or more correctly "visual-orthographic") forms of new words—"orthographic learning"—is a surprisingly rapid and durable process.

In this chapter, I ask how this learning comes about, focusing on a particular theory of orthographic learning—the self-teaching hypothesis. In the first section, I provide an exposition of the theory. This is followed by a review of the empirical studies that others and I have undertaken in attempting to test this idea.

But why all the fuss about spellings in an age where "correct" spelling seems out of vogue. Today's writers—young and old—have automatic spelling-correction routines at their fingertips, spell-checkers if need be, and even if it is an old-fashioned pencil-and-paper production, we are urged to tolerate creative ("invented") spellings particularly among novice readers/writers. The final straw, of course, is the SMS text-messaging jargon which seems to throw all known spelling conventions to the wind. So what difference does it make if we remember *Sloak* rather than *Sloke*? The answer is that it is not really about spelling but about *reading*, indeed, the very foundations of skilled reading, text understanding, and ultimately literacy.

B. THE CRUCIAL ROLE OF ORTHOGRAPHIC LEARNING IN THE ACQUISITION OF SKILLED READING

Perhaps the single most distinctive characteristic of skilled reading is the sheer speed and effortlessness of the word identification process. While there is no disputing that comprehending the meaning of complete units of text (from brief phrases such as *Staff Only* through to a 2-volume Harry Potter novel) is the ultimate goal of reading acquisition, the component word recognition processes apparently constitute a unique and crucial ingredient in this process. Consider the existence of severely dyslexic yet highly intelligent and literate individuals (see, e.g., Eileen Simpson's inspiring autobiography) as well as underprivileged groups such as women in traditional societies who, despite normal intelligence and linguistic capabilities, were (and in some countries still are) denied the opportunity to learn to read and write (see, e.g., Lukatela *et al.*, 1995). What is lacking in both these groups are not the capabilities needed to comprehend written language but the specific ability to deal with print, namely, the ability to recognize the printed word. Of course, although word recognition proficiency is a pre-requisite for literacy learning, it is no guarantee of good text understanding. Highly skilled word decoders—so-called hyper-lexics (the mirror image of dyslexia)—are distinguished by their exceptional word reading ability, yet their low intelligence and particularly poor language comprehension renders them unable to comprehend the material they decode so well (Nation, 1999).

The ability to instantly and effortlessly recognize the printed word is, in many ways, the quintessence of reading skill. Such "technical" expertise or "automaticity" seems to be a defining feature of most human skills—not just reading. Consider the envy of the novice driver marveling at how the veteran motorist manages to carry on a near-seamless conversation while negotiating city traffic, or the novice pianist who observes (often in despair) at how easily a technically challenging passage currently beyond her current level of prowess is executed by the teacher with finesse and apparent effortlessness. The art of skilled word recognition, when practiced by a highly literate individual is so efficient or "automatized" it seems almost "unstoppable"—occurring whether we will it or not. It has even been shown that printed words can be recognized without conscious awareness (see, e.g., the subliminal phenomenon called "masked priming," Forster & Davis, 1984). Indeed, roadside billboard advertising seems predicated on precisely this automaticity—if the print is clearly visible and the graphics sufficiently eye-catching, the driver just cannot avoid taking in the advertiser's message (see Logan, 1988).[1]

Such accomplished word recognition depends on the accumulation of a large mental store of printed word forms ("representations"), each encapsulating the knowledge that a particular configuration of letters such as *Sloak* (as opposed to other similar-looking ones such as *Slook*, *Sleek*, *Slack*, *Cloak*, *Soak*, *Look*, etc.) is the written form of a word identified in speech as "sloak" and referring to the name of a mythical outback Australian town. The skilled reader has at his or her disposal thousands of these internal so-called "orthographic representations," not to mention a good general knowledge of orthographic (spelling) conventions. In the classroom these representations are called a reader's "sight" vocabulary, in the reading researcher's laboratory—the "orthographic lexicon" or "orthographic processor." Whether this knowledge is best captured in individually stored word-level units—so-called localist models (see, e.g.,

[1]The reader familiar with Gough and Hoover's so-called "Simple Model" of Reading will no doubt recognize the well-known notion that reading comprehension consists of two components—decoding and linguistic comprehension, but even this oversimplified model still seems a useful way of framing the issue.

Coltheart *et al.*, 1993, 2001)—or as a distributed (i.e., non-localist) set of connections in a multi-layered network of simple neuron-like units (so-called "triangle") models (Harm & Seidenberg, 2004; Plaut *et al.*, 1996), there is a broad consensus that orthographic representations specifying the identity and order of a word's letters (Adams, 1990; Ehri, 1980, 1992; Perfetti, 1992) and tightly linked to word identity—phonology, meaning (and more)—are the key "skill" in skilled reading and that compiling this orthographic knowledge is the main challenge facing the novice reader.

To sum up, orthographic learning is the very nucleus of print processing. But how do readers manage to compile such impressive repositories of orthographic knowledge? This brings us to the self-teaching hypothesis. The self-teaching hypothesis is simply a theory about how readers build up this knowledge—a process that takes place not over months but many years and probably never stops.

II. The Self-Teaching Theory of Orthographic Learning

The self-teaching hypothesis (Firth, 1972; Jorm, 1979; Jorm & Share, 1983; Share, 1995) proposes that the ability to translate unfamiliar printed words into their spoken equivalents ("phonological recoding" or simply "decoding") is the central means by which orthographic representations are acquired.[2] Each successful decoding of a new word is assumed to provide an opportunity to acquire the word-specific orthographic information that is the foundation of skilled visual word recognition. Exhaustive phonological recoding is assumed to be critical for the formation of well-specified orthographic representations because it draws the reader's attention to the graphemic detail—the order and identity of the letters and how they map onto the phonological representation—the spoken form (see Ehri, 1992, 2005; Perfetti, 1992). In this way, phonological recoding functions as a self-teaching mechanism or built-in teacher enabling a child to

[2]As originally pointed out (Share, 1995, footnote 1, p. 152) the term phonological recoding does not imply any particular procedure but is used as an umbrella term for the process of print to sound conversion *by whatever means this is accomplished.* This covers several possibilities including (but not necessarily limited to) explicit letter-by-letter application of grapheme–phoneme correspondence rules, an analogical activation-synthesis mechanism, an implicit statistical learning mechanism, or automatic activation of a distributed (connectionist) network of simple neuron-like units. Although often misinterpreted in this way, the self-teaching hypothesis *does not* imply that orthographic learning is solely the product of the first of these procedures. Furthermore, the nature of this process will undoubtedly vary developmentally and across orthographies.

independently develop the word-specific orthographic knowledge necessary for skilled reading.

The self-teaching idea is a little unconventional in that the process of orthographic learning is assumed to take place unintentionally, as a by-product of the process of decoding—readers do not usually aim to analyze and remember spellings, it just happens and probably without our being aware of the process. It is important to note too that the self-teaching idea rejects the intuitively appealing notion that identities of most new printed words can be directly taught (by teachers, parents, or peers) or can be guessed on the basis of contextual information (see Share, 1995 for detailed discussion). Only decoding seems to offer a sufficiently reliable means for identifying novel letter strings (owing to the fundamentally alphabetic nature of the written code) thereby providing the opportunities for (incidental) learning of the visual form (spellings) of these items.

A. SOME HISTORICAL BACKGROUND

At the time that the self-teaching notion was first conceived, the role of phonological recoding was seen solely as a back-up mechanism for word recognition when "direct" visual recognition failed (e.g., Coltheart, 1978; McCusker, Hillinger, & Bias, 1981). The dominant conceptual framework at the time was the classic "either-or" dual-route notion of two independent routes (now eschewed by Coltheart in favor of a more synergistic "two-hoses-filling-a-bucket" notion, see Coltheart, 2005). Because the focus of traditional dual-route theorizing was the skilled reader who already possesses extensive orthographic knowledge, this back-up route clearly had only subsidiary status in skilled word recognition, although there was broad agreement that for the beginning reader phonology was somehow more important (e.g., Barron, 1986; Doctor & Coltheart, 1980), because among less experienced readers many more words are unfamiliar.

The self-teaching notion was originally conceived by a doctoral student named Ian Firth—one of a long line of researchers (both preceding and succeeding him) to discover, or rather re-discover, the remarkable power of pseudoword naming to discriminate good and poor readers.[3] Firth proposed that the ability to convert letters into sounds as a means to pronouncing unfamiliar words was the way a child built up the range of words recognized

[3]Even today, I stand in awe of Firth's colossal dissertation which included one of the first (if not the very first) computational models of reading—a computer simulation remarkably similar to Ans, Carbonnel, and Valdois' (1998) contemporary multi-trace model. Unfortunately, this thesis was never published.

by "sight." Thus, decoding was the key to reading acquisition and the development of a child's sight or reading vocabulary. At that point in the history of developmental reading research, the phonological deficit hypothesis was unknown and visual/perceptual theories (eventually laid to rest some years later by Vellutino, 1979) were pre-eminent. Firth's pseudoword naming data, therefore, was an unexpected finding that needed explaining in an era of visual/perceptual theories of reading difficulties.

Developing the self-teaching notion, Jorm and Share (1983) pointed to a growing body of findings indicating a major role for phonological recoding and, more generally, information processing (perception, learning, and memory) in the speech domain (see also Jorm, 1983). As already noted, the dominant thinking at the time regarded printed word recognition as a mainly visual affair. Like Firth, Jorm and Share (1983) were puzzled by the apparent contradiction, or paradox, between predominantly visual/non-phonological skilled word recognition favored at the time (Coltheart, 1978; Glushko, 1979; Kay & Marcel, 1981; McCusker *et al.*, 1981) and a growing body of developmental evidence pointing to a central role for phonology in reading. The self-teaching idea was a way to resolve this (apparent) paradox. It was conceded that visual word recognition, at least among skilled readers, and at least for familiar words, was largely if not exclusively a visual process[4] but argued that the acquisition of this knowledge base was largely the result of decoding encounters with new words—phonological recoding. Jorm and Share stressed the fact that children are continually encountering unfamiliar words, and consequently require a means for independently identifying these orthographic newcomers, which are simply too abundant to be taught on a one-by-one rote basis (the direct instruction option) nor could be guessed accurately enough on the basis of contextual information (for reasons elaborated in Share, 1995). This left only the recoding mechanism to fulfill the "self-teaching" function of enabling children to independently decipher novel letter strings and, in the spirit of paired-associate learning, permit bonding of the visual form of the word to its spoken and semantic form.

At first, the proposed self-teaching process was conceptualized in rather mechanistic/behavioristic terms as a "learning trial" in which successful decoding of a printed word permitted associative pairing of the new visual form with its spoken form and meaning (see Jorm & Share, 1983). This paired-associate learning process—like the dominant dual-route model—was rather vague about what actually was acquired.

[4]Today, the pendulum seems to have swung back to a much stronger phonological position (see, e.g., Frost, 1998; Perfetti, 2003; Van-Orden, Pennington, & Stone, 1990).

The emphasis was on the *how* of orthographic learning, rather than *what* was actually learned.

Jorm and Share (1983) were at pains to point out that natural text is replete with low-frequency words not only for beginning readers but also for more experienced readers (see also Foorman *et al.*, 2004). Share (1995) however, noted that, at some point, *every* printed word, even a child's own name, is unfamiliar visually.[5] Thus, self-teaching, it was argued, was relevant to the process of learning *every* printed word.[6]

A subsequent conception of the self-teaching idea recast the self-teaching function of phonological recoding within the broader more universalistic framework of a transition from initial identification (decoding) of unfamiliar words to their rapid recognition as familiar units. Share (2007) argues that this "unfamiliar-to-familiar" transition (seen from the perspective of individual items) or (from the reader's perspective) "novice-to-expert" transition represents a fundamental and overarching duality in word reading that applies to *all* words in *all* possible orthographies.

On the one hand, because *all* words are novel at some point in reading development, the reader must possess some algorithm, albeit imperfect, yet nonetheless functional for *independently* identifying words encountered for the first time in everyday reading. Secondly, and again a literacy universal, the reader must eventually be able to achieve a high degree of automatization in word recognition—rapid and effortless recognition of familiar words and morphemes (LaBerge & Samuels, 1974; Logan, 1997, 2002; Perfetti, 1985; Rayner, 1998; van der Leij & van Daal, 1999) perceived as whole units via a direct-retrieval mechanism (see Ans *et al.*, 1998; Weekes, 1997). Here is where the well-specified "autonomous" orthographic representations discussed previously are crucial (Perfetti, 1992). This ability to automatize or "modularize" word identification (Adams, 1990; Stanovich, 1990, 2000) is probably the quintessence of reading *skill* (Perfetti, 1985, 1994). As with the decoding algorithm, this high-speed direct-retrieval mode applies to *all* words in *all* orthographies.

This universalistic dualism has several advantages over the traditional Coltheart/Baron dual-route approach that focuses primarily on the peculiarly English-language distinction between regular and irregular words. First, it merges the study of reading with the study of human skill learning across a range of domains (see, e.g., Anderson, 1981; Goldstone,

[5]Until recently my own name, printed in the original Czech, complete with hacek—Šer, was visually unfamiliar.

[6]This is almost but not quite correct. The most frequent 100 or so words in printed English (*was, is, are, to, of*) are extraordinarily irregular but pop up in almost every phrase—hence may well be learned or taught whole-word rote style.

1998; Karni, 1996; LaBerge & Brown, 1989; Logan, 1988; Newell & Rosenbloom, 1981; Shiffrin & Schneider, 1977; Siegler, 1988; Venezky, 2006). The dualism common to all skill learning is a contrast between, or transition from slow, deliberating, step-by-step unskilled performance to rapid automatized one-step or "unitized" skilled performance without which the "skill" of reading would probably never have made so profound an impact on modern knowledge-based cultures (Olson, 1994). Second, this broader "novice/expert" or "unfamiliar/familiar" dualism also converges with the dualistic nature of an efficient orthography. Specifically, an efficient script can be conceptualized as a compromise between the often competing needs of the novice and the expert reader (Rogers, 1995; Venezky, 2007). This orthographic dualism might be termed the "decipherability/automatizability" criterion.

An effective orthography must first provide the reader with a means for deciphering new words *independently*. This applies to both the young child new to the world of print, and to the skilled reader encountering a new or unfamiliar word. Furthermore—and this is crucial to skill learning in all domains—this algorithmic process must lay the foundations for the rapid direct-retrieval mechanism. This "do-it-yourself" or "self-teaching" function of decoding is probably the chief virtue of alphabetic scripts—supplying not only an economical means for identifying new words (via print-to-sound translation), but, critically, establishing the detailed orthographic representations on which rapid fully unitized skilled word recognition is founded. Secondly, a successful script must also answer to the needs of the expert by providing visually distinctive word-specific (or morpheme-specific) visual-orthographic configurations required for the unitization and automatization of skilled word recognition. Ideally, each morpheme should have one and only one representation (morpheme "constancy") without showing morphophonemic variation (e.g., *electric/electricity/electrician*), with different morphemes represented differently (morpheme "distinctiveness") (Rogers, 1995).[7,8]

A script catering primarily to the needs of skilled readers, such as the pre-communist Chinese characters (and in many respects English

[7]English is faithful to the distinctiveness principle in its heterographic homophones (*blue/blew*) but not in the large numbers of polysemous (homographic) homophones (*well/well/well*) or the relatively rare heterophonic homographs (*wind/wind*).

[8]There are clearly advantages for a script that also maintains morpheme "constancy"—the same morpheme always written the same way—but it may be morpheme *distinctiveness* that is crucial for the automatization of word recognition. In other words, it's not that the *w* in *two* is important for revealing morphemic relations (e.g., *twelve, twice, twilight)*—a highly doubtful assumption for the young reader—but that this etymological quirk provides distinct spellings for potentially confusable homophones (*too/two/to*).

orthography—see Chomsky & Halle, 1968) will pose enormous challenges for the novice. Conversely, a script providing maximum decipherability for the novice—Korean hangul, Japanese kana, or highly regular pedagographies such as i.t.a—will often fail (as a stand-alone script) to meet the needs of the skilled reader, primarily owing to homophony. (Consider the problems incurred if *two*, *too*, and *to* all shared the same spelling—*tu*.)

To sum up, the alphabetic code furnishes the necessary algorithm—a self-teaching mechanism permitting independent identification by means of decoding that lays the foundations for the skilled reader's word recognition expertise via the establishment of autonomous orthographic representations.

Four central features of the self-teaching theory are reviewed next.

B. KEY FEATURES OF SELF-TEACHING

1. Self-teaching is Item-based, Not Stage-based

In their earlier review of the (inconclusive) evidence for and against stage models of word recognition development, Jorm and Share (1983) proposed that many of the conflicting findings might be resolved by considering item familiarity—high-frequency words can be rapidly recognized visually but unfamiliar items depend more on phonology. They suggested that the pertinent question was not *how* children identify words, but how they identify *which* words. Because word-specific orthographic knowledge is acquired so quickly (Hogaboam & Perfetti, 1978; Reitsma, 1983a; Share, 1999, 2004), even among inexperienced readers, words seem to be rapidly assimilated to a child's reading or so-called sight vocabulary. This implies that at any one point, a child will be reading some words (the most common) rapidly via primarily direct visual/orthographic recognition, whereas other less familiar words are processed primarily phonologically. Furthermore, this item-based learning appears to begin very early (consistent with the early onset hypothesis, described subsequently) and may well be a never-ending process since unfamiliar printed words are continually being encountered even by skilled readers. The unfamiliar-to-familiar transition discussed previously implies experiential item-by-item learning. This aligns well with instance-based theories of learning such as Logan's (1988) and the multi-trace computational model of skilled reading of Ans *et al.* (1998), which see the process of learning as highly dependent on "episodic" encounters with specific stimuli. In the Ans *et al.* model, for example, (as with Firth's simulation) the "default" mode of word recognition for familiar words is global (whole word or lexical), but analytic

(either at the syllable or letter level) in the case of unfamiliar words. (It remains to be seen to what extent this global/analytic dichotomy aligns with the phonological/orthographic dichotomy.) Once again, the key element in this learning process, as with all skill learning is the unfamiliar-to-familiar, unskilled-to-skilled transition. Of course, recognition strategies at the level of *individual* words could, if one insists, be conceived of as a "stage-like" progression from one strategy or mode to another, but not at the level of reading in general as in traditional stage theories (see, e.g., Frith, 1985). The emphasis on item-level changes, however, does not preclude developmental changes in the *process* of deciphering new words—these are captured by the lexicalization idea.

2. Lexicalization

Many discussions of the reading process seem to imply that phonological recoding is a single unvarying routine or set of routines. In contrast, the notion of lexicalization regards phonological recoding as a developmental process, particularly among English-language speakers/readers for whom this learning process probably stretches on indefinitely. The evidence reviewed by Share (1995) indicates that most English-language readers seem to start out with a relatively simple set of one-to-one letter–sound correspondences that are relatively insensitive to orthographic and morphemic context. These initial correspondences are often invariant and therefore, strictly speaking, incorrect. Yet, they offer the novice a manageable set of correspondences capable of generating an approximation to an identifiable pronunciation, one (and later, perhaps more) that can be checked for contextual "goodness of fit." With increased print exposure, these "beginner" letter–sound correspondences become "lexicalized," that is, modified in the light of lexical constraints imposed by a growing body of orthographic knowledge. The growing print lexicon alerts the child to regularities beyond the level of simple one-to-one correspondences, such as context-sensitive (soft and hard *g* and *c*), positional (final versus initial *y*), and morphemic constraints (*missed* rather than *misst*). Thus, contrary to prevailing opinion, this view posits no single decoding procedure or routine, but an ever-changing and self-refining process that at first appears be very "bottom-up," with little sensitivity to higher-order regularities but over the course of print experience becomes increasingly attuned ("lexicalized") to the given orthography in a two-way interplay between decoding abilities and orthographic knowledge.

3. Early Onset

Another key feature of self-teaching is early onset; beginning reading is assumed to be beginning self-teaching. Several studies suggest that some decoding skills may exist at the very earliest stages of learning to read, even before a child possesses any decoding skill in the conventional sense of being able to sound out and blend even simple pseudowords (Ehri & Wilce, 1985, 1987; Morris, 1992; Stuart & Coltheart, 1988). This view runs counter to many contemporary accounts of printed word learning that propose an initial logographic or visual stage prior to later-developing phonological recoding (see, e.g., Frith, 1985; Gough & Juel, 1991). The early onset hypothesis proposes that even some rudimentary decoding ability may be sufficient for the establishment of primitive or partial orthographic representations of the kind discussed by Ehri (1992) and Perfetti (1992). This early self-teaching depends on three factors; letter–sound knowledge, some minimal phonological sensitivity in the form of awareness of initial sounds (or initial and final sounds which are typically the more regular consonants), and the ability to utilize contextual information to determine exact word pronunciations on the basis of an incomplete or inaccurate decoding.

On the thorny question of the role of context, there is a critical distinction to be drawn between the *identification* of an unfamiliar letter string (the early self-teaching discussed here) as opposed to the *re*cognition of a familiar string. The early onset idea proposes an important supplementary or facilitative role for context in the *initial learning* of newly encountered words (especially in English)—this is quite unlike its role in the largely autonomous recognition of familiar (well-unitized) words that no longer require "outside" (supra-lexical) assistance. That is, the reliance on context in the case of unfamiliar words, especially irregular ones, can be helpful in orthographic learning by resolving decoding ambiguity, but, later, as word recognition becomes more modularized (Shatil & Share, 2003) can be discarded much like the young bicycle rider's training wheels; disabled readers, however, seem unable to discard the contextual "crutch" owing to poorly automatized word recognition.

4. Two Components to Self-teaching—Phonological and Orthographic and the Phonology-Primary/Orthography-Secondary Hypothesis

The process of self-teaching is not just about decoding but seems to involve at least two component processes—phonological and orthographic. Both components are assumed to make independent contributions to printed word learning although the phonological component is considered primary, accounting for the largest portion of the variance in individual differences in reading ability. The orthographic component represents an additional, independent but *secondary* component. The phonological component is simply the ability to use knowledge of spelling–sound relationships to identify unfamiliar words. Phonological recoding is, of course, a reading sub-skill, and as such is assumed to reflect both instructional/environmental factors such as teaching method and print exposure as well as basic underlying cognitive/linguistic processes such as phonological memory and phonological awareness. The ability to translate print to speech is a necessary but not sufficient condition for orthographic learning. This point is worth reiterating: decoding skill creates opportunities for self-teaching but does *not* guarantee that orthographic learning will take place. Over and above the ability to decode unfamiliar words, there exist individual differences in the speed and accuracy with which word-specific (and general orthographic) knowledge is assimilated (Cunningham, Perry, & Stanovich, 2001).

The common metric of orthographic ability is typically spelling knowledge (routinely assessed with tasks such as orthographic choice or homophone choice). These measures of what might be termed "crystallized" orthographic ability reflect not only the basic visual analysis or visual attention and memory abilities that presumably determine how quickly and accurately orthographic representations are established[9] but also instructional/environmental and print exposure variables. The contribution of visual/orthographic ability to the development of word-specific orthographic representations, however, will depend heavily on the successful operation of the phonological component. Thus, visual/orthographic ability is seen not merely as a second source of variance, but as a *secondary* source of individual differences in printed word learning, hence the "phonology-primary/orthography-secondary" hypothesis.

III. Empirical Findings

A modest number of studies have now been undertaken on the general topic of orthographic learning; some of the later work focused specifically on the self-teaching hypothesis addressing issues raised in the previous section. Some of the findings have proven surprisingly robust, others remain intriguing puzzles, while many more are merely research questions awaiting investigation. Although no direct test of the self-teaching hypothesis was carried out until the end of the 20th century (see Share,

[9]This question remains the "black box" or perhaps even the *bette noire* of orthographic learning—the present literature is still in resplendent disarray, (see, e.g., Bosse, Tanturier, & Valdois, 2007; Burt, 2006; Castles & Coltheart, 1996; Castles & Nation, 2006; Cestnick & Coltheart, 1999; Goulandris & Snowling, 1991; Hawelka & Wimmer, 2005; Williams, *et al.*, 2003).

1999), a small number of pioneering studies of orthographic learning reported experimental data consistent with the self-teaching hypothesis.

A. THE EARLY PIONEERS

The first study of orthographic learning among developing readers was undertaken by Hogaboam and Perfetti (1978, Experiment 2). Fourth graders were taught a set of printed pseudowords presented either aurally or in print, then practiced these items at least 15 times over a period of three days. No child was asked to read the printed pseudowords independently—all pronunciations were given and the child asked to repeat them. A day later, both groups named the items that had been seen and pronounced in printed form faster than the items that were only heard and spoken, and this advantage was maintained at 10-week retest. There was no effect of meaning. The orthographic learning effect was further explored in a follow-up study with third graders who received 0, 3, 6, 9, 12, or 18 exposures to pseudowords presented either aurally or visually (meaning was dropped). Evidence of orthographic learning was obtained at each of the five exposure conditions although the differences in naming latencies did not reach significance possibly owing to the small sample sizes ($n = 5$).

In another trail-blazing study, Ehri and Roberts (1979) taught first graders to pronounce eight pairs of printed homonyms (e.g., *rows/rose*), each practiced 16 times over the course of several sessions either in context or in isolation. The pre- to post-test gains for word reading accuracy and spelling choice suggested that orthographic learning had occurred. A later study (Ehri & Wilce, 1980) replicated and extended these findings to a set of context-dependent function words (e.g., *might*, *while*, *must*, *from*, *enough*).

The most comprehensive series of pioneering studies into orthographic learning was carried out in Dutch by Pieter Reitsma. In his first experiment, Reitsma (1983a) taught third graders pseudoword names for fictitious animals and fruits. Half of these items were presented auditorily and half both auditorily and visually. Test items were then presented visually in a semantic (animal/fruit) categorization task in which all items appeared six times. Classification times for the items not seen in printed form were significantly slower only for the first three presentations. That is, by the fourth trial, response latencies had effectively converged with the items learned in both spoken and visual form, suggesting rapid orthographic learning in the context of (silent) reading for meaning.

In a second study (Reitsma, 1983a, Experiment 2), second graders were first familiarized with the spoken forms of a set of pseudowords before being taught to read the printed word. Each item was then practiced (in isolation) either four or eight times. Three days later, target spellings were named significantly faster than homophonic spellings but only for the group who practiced reading the targets eight times. A third study (Experiment 3) compared word learning in skilled and unskilled first grade readers and an older reading age-matched group of disabled readers. Twenty words judged to be familiar in spoken form but unfamiliar in print were presented in meaningful sentences which were read and reread two, four, or six times over two successive days. Three days later, both the original spellings and homophonic spellings were presented for naming. Both groups of first graders read the target spellings more quickly and more accurately for words practiced at least four times. There was no evidence of orthographic learning among disabled readers either in naming speed or accuracy.

In two further follow-up studies summarized in Reitsma (1989), normal first graders and older reading age-matched disabled readers again practiced reading unfamiliar real words 0, 2, 4, or 6 times. As before, the younger beginning readers, but not the older disabled readers, showed the familiar divergence in target/homophone naming times with increasing practice. In contrast to the earlier study, a naming time difference was already apparent after only two exposures. Response time differences for words and homophones as a function of practice were also correlated significantly with scores on a word reading fluency test for both groups of readers. A significant correlation between naming time differences and performance on a test of oral pseudoword repetition led Reitsma to conclude that acquisition of word-specific knowledge depends partly on efficient phonological processing.

In a second experiment, normal first graders and older disabled readers practiced reading unfamiliar real words 0, 3, 9, or 18 times. In this study, the naming time effect was again evident among the normal readers but only after nine (but not three) exposures. Once again, there was no evidence of orthographic learning among the older disabled readers even after 18 exposures. The effects of phonemic (cross-modal) priming were found to decline with increasing practice for the normal beginners suggesting that their acquisition of word-specific orthographic information was accompanied by a diminishing reliance on phonology. For disabled readers, the benefits of a related phonemic prime were consistent across all exposures.

The final "pre-self-teaching" study to be summarized here was carried out by Manis (1985). In the course of four sessions, normal and disabled Grade 5 and 6 children were first taught the meanings and pronunciations of low-frequency (real) words varying in regularity and length then presented with their printed forms for pronunciation. All errors were corrected and reread. In three further sessions, children were retrained briefly on the test items before being given two naming tasks (immediate and delayed). By the third test session (after at least eight visual exposures), naming accuracy and speed among the normal readers (but not the disabled readers) had effectively converged on the naming times for a set of high-frequency control words. Declining regularity and length effects also suggested that word-specific orthographic information had become rapidly assimilated by the normal readers.

Collectively, these studies demonstrate impressive convergence—a rare phenomenon in pioneering work yet one indicative of highly robust effects: surprisingly few exposures appear to be sufficient for the acquisition of word-specific orthographic information among normal readers, but not disabled readers. These training outcomes, furthermore, are consistent with several earlier studies examining the issue of phonological versus visual "routes" among beginning readers which found that even beginning readers are apparently able to read highly familiar words via direct visual recognition with minimal involvement of phonological assembly processes (Barron & Baron, 1977; Condry, McMahon-Rideout, & Levy, 1979; Rader, 1975).

Not only did this early research attain consensus regarding the rapidity and durability of early printed word learning, it also suggested that as children acquire word-specific orthographic representations the role of phonology diminishes, consistent with the item-based transition from word identification that is heavily dependent on phonology to more visual-orthographic recognition (Manis's declining regularity and length effects, and Reitsma's, 1989, sound priming data, see also Harm & Seidenberg, 2004). The fact that training/learning effects revealed in these investigations were uniformly item-specific and did not extend to untrained control items represents strong support for the item-based view of orthographic learning espoused previously.

Summing up, all the experimental investigations reviewed here are certainly consistent with the hypothesis that word-specific orthographic representations are acquired *by virtue of the self-teaching opportunities afforded by successful decoding*. These data are nonetheless inconclusive on the self-teaching issue for reasons that will become apparent in the presentation of the next set of studies, all of which examined orthographic learning through the lens of the self-teaching hypothesis.

B. STUDIES OF ORTHOGRAPHIC LEARNING WITHIN THE SELF-TEACHING FRAMEWORK

The first test of the self-teaching hypothesis was a non-experimental longitudinal study carried out by Jorm *et al.* (1984). In the context of a large-scale longitudinal study of over 500 Australian children followed from the end of Kindergarten—the first year of formal reading instruction in the state of Victoria—28 children who had a score of 0 on a test of pseudoword reading but a score of 5 or more on a composite measure of sight word reading were individually matched to children scoring 4 or more on pseudoword reading. To guard against regression to the mean, children were also compared on a second sight word reading measure (on which they had not been matched) but were still found to be well matched. A year later, the "early decoders" had drawn ahead on the second sight word list and were significantly superior on the Neale test of word reading accuracy. The two groups were found to diverge even more a year later at the end of Grade 2—the gap in reading age doubling between Grade 1 and Grade 2. (It was unfortunately not possible to include pairs of groups matched on decoding but differing in sight word reading.)

Although this study clearly demonstrated that decoding is valuable in reading acquisition, as the authors acknowledged, it provided no direct evidence for the self-teaching interpretation of these data. Direct evidence was only supplied some years later in a series of studies following in the footsteps of the earlier experimental work reviewed above.

The first experimental study within the self-teaching framework was carried out in Hebrew by Share (1999) employing the same basic experimental paradigm used by Reitsma (1983a) but with some significant variations. First, in contrast to prior studies in which target words were presented either in isolation or in isolated sentences (read and often reread), Share aimed to present targets in as natural a setting as possible by constructing short "stories" like the one at the beginning of this chapter. Children were specifically instructed to read for meaning and told they would be questioned about the content of the story following reading. They were also asked to decide which story they liked the most. A second innovation was the switch to unassisted reading—previous work had either explicitly taught participants the pronunciation of target strings or had corrected errors, often asking the child to repeat the corrected pronunciation. Among young readers of Dutch—a moderately regular orthography—this is not a devastating problem (see Seymour, Aro, & Erskine, 2003) because the vast majority of test items would be expected to be decoded correctly without assistance (probably between 80% and 90%). In the English-language investigations, by contrast, many—perhaps *most* items (see Seymour *et al.*, 2003)—would probably *not* have been decoded without help. Thus the generalizability of the English-language findings to naturally occurring unassisted text reading is in doubt.

It is also important to note that in all this work, the experimental procedure *obliged* the child to decode all target strings. Self-teaching is assumed to operate when a child is independently reading connected text for meaning. In everyday reading therefore, children may (a) choose to ignore unfamiliar words which can often be skipped without penalizing overall comprehension, (b) may guess (correctly or incorrectly) on the basis of prior context and/or prior knowledge, or (c) make *uncorrected* misreadings. Share (1999) observed that a massive body of evidence shows that normal young readers are *able* to phonologically recode novel letter strings such as pseudowords *when obliged to*, but not a single study directly demonstrates that this knowledge is actually applied in independent reading. It is essential therefore to demonstrate that phonological recoding is actually employed even when the child is free to resort to these alternative options. Accordingly, in this first direct test of the self-teaching hypothesis, no mention was made of the target words either before or after text reading—even the comprehension questions took care not to mention the target words but focused on the semantic content of the text. Needless to say, all targets appeared in the same typeface as the rest of the text. Children who sought help from the experimenter were encouraged to read the word as best they could by themselves.

The Share (1999) study also addressed a second shortcoming of the pioneering word-learning studies reviewed above. Orthographic learning may be attributable to mere visual attention to the target strings rather than to the decoding process *per se*. Although Reitsma's (1989) finding of significant correlations between orthographic learning on the one hand and both oral reading fluency and oral pseudoword repetition on the other is certainly suggestive, this alternative hypothesis is difficult to rule out in any of the early studies. The visual inspection hypothesis was directly investigated by Share (1999, Experiments 2, 3, and 4) and, subsequently, by Kyte and Johnson (2006).

The targets in Share (1999) were all novel letter strings (pseudowords) embedded in passages such as the one at the beginning of this chapter. These pseudowords appeared either 4 or 6 times per text in two homophonic spellings; half the sample saw one version in the relevant text (e.g., *Sloak*) while the other half saw the alternate spelling (*Sloke*). As a further precaution, pre-existing spelling preferences were examined with a spelling preference or "wordlikeness" task administered to a comparable group of children who did not participate in the main study. Only pairs of spellings that demonstrated a balanced preference—close to 50:50—were used. According to the self-teaching hypothesis, even when unassisted, children will apply their knowledge of letter–sound correspondences in order to derive the pronunciation of these unfamiliar words and, if successful, will begin to acquire knowledge of their orthographic forms such that the correct form will be recognized and recalled beyond chance on future occasions.

Three days later, orthographic learning was assessed in three ways; orthographic choice (from among four alternatives; the original spelling, a homophonic foil, and two non-homophonic spellings), naming accuracy and speed for the target and homophonic foil, and spelling production. The second graders participating in this experiment correctly decoded the targets (at the consonantal level) on 84% of occasions. This level of consonantal accuracy will seem rather high to readers familiar with the reading accuracy of young readers of English, but this figure is standard for Hebrew's highly regular pointed script (see Share & Levin, 1999) or, indeed, for most other regular orthographies (see Seymour *et al.*, 2003). In the 4-alternative orthographic choice task, the original target spellings were correctly selected well beyond the 25% chance level (74%). Naming times for the original spellings were also significantly faster for the learned spellings than for the homophonic spellings, with no differences in error rates. Finally, on the spelling measure, the correct spelling was reproduced in its entirety on 41% of occasions compared to only 10% for the homophonic spelling. When spelling was scored on a per-letter basis as opposed to a whole-word basis, correct target letters were reproduced on 67% of occasions compared to only 29% for homophonic letters. The overall pattern of results held for both the 4- and 6-exposure conditions with only small non-significant advantages for the 6-exposure condition. These results replicate the pioneering work on orthographic learning and indicate that very few exposures (four or even less) to a target spelling are sufficient for orthographic learning to occur. This study also extends this finding to unassisted (oral) reading of connected text.

Experiment 2 examined the alternative visual exposure hypothesis by presenting target strings under conditions designed to allow visual inspection but minimize phonological processing. Children performed a lexical decision task (deciding whether a letter string is a real word or not—a task known to induce relatively shallow, primarily orthographic processing)—with irrelevant concurrent vocalization (saying the pseudoword *dubba* over and over) with target exposure limited to 300 ms. Second graders showed themselves quite capable of performing this task (lexical decision accuracy averaged 90%) but it was clear that phonological recoding was only reduced, not eliminated. Brief visual inspection was sufficient to produce reliable orthographic learning in orthographic choice and spelling, but there was no significant advantage for original spellings in naming accuracy or times. The levels of orthographic learning were significantly inferior to the levels observed in Experiment 1 with unlimited exposure to orthographic targets.

There still remained the possibility that the attenuated but significant orthographic learning in this second experiment might be attributable to visual inspection alone but diminished owing either to brief visual exposure and/or presentation without supporting context. Experiment 3 evaluated this possibility by asking children to name (i.e., phonologically recode) the same briefly presented items. Comparison of the outcomes of Experiments 2 and 3—orthographically *relevant* pronunciation (Experiment 3) versus *irrelevant* articulation under the same conditions (brief decontextualized exposure)—provided a relatively clean test of the contribution of phonology to orthographic learning.

The results showed that second graders, once again, proved themselves up to the challenge—correctly pronouncing the briefly exposed targets on 72% of trials compared to 86% for the corresponding (6-exposure) condition in the non-time-limited story-reading condition in Experiment 1. Phonological recoding of the same targets under similar conditions to Experiment 2 produced significantly greater orthographic learning than orthographically irrelevant vocalization in Experiment 2, pointing to a unique contribution of phonological recoding and indicating that the results of Experiment 1 cannot be attributed solely to visual exposure, although some role for pure visual attention *per se* cannot be ruled out by this pair of studies.

As pointed out by Kyte and Johnson (2006), however, the comparison between Experiments 2 and 3 is confounded by the different task requirements of reading aloud and lexical decision. In a fully within-participant design, Kyte and Johnson (2006) had fourth and fifth graders perform a lexical decision for real words and pseudoword targets under two conditions: a read-aloud condition designed to maximize phonological recoding of target strings and a concurrent articulation condition designed to minimize phonological recoding yet allowing sufficient visual-orthographic processing to occur for lexical decision. Pseudoword targets appeared six times in two alternate spellings: half the sample saw one spelling and half the other. Brief (and masked) exposures were also used (400 ms). Lexical decisions were very accurate and very similar in the two conditions: pronunciation accuracy in the naming condition was 95%. A day later, orthographic choice revealed a significant advantage for the read-aloud condition with condition accounting for around 20% of the variance. Spelling produced stronger effect sizes, ranging from 37% to 45%. The post-test naming latency data revealed a significant advantage of condition for item means but not participant means. Kyte and Johnson's (2006) more rigorous design provides strong support for the role of phonology in orthographic learning.

Returning to the question of the contribution of "pure" visual exposure to orthographic learning, Share (1999) conducted a fourth experiment using non-alphabetic symbol strings (e.g., ?+*$) that offer no possibility of

recoding. These strings were presented in a combined letter search and string length judgment task in an effort to approximate the item (letter) level and string (word) level processing assumed to occur in phonological recoding. Three days later, orthographic choice indicated that target strings were recognized correctly on 33% of occasions. This figure was not significantly superior to the foils designed to be parallel to the homophone foils in Experiment 1 (28%), but it was significantly beyond chance (25%). Clearly, however, the magnitude of this effect, if indeed reliable, signifies only a small proportion of the overall learning effect observed following phonological recoding. This result accords with other studies underscoring the extraordinary difficulty involved in memorizing strings of non-alphabetic symbols containing common visual elements (e.g., Ehri & Wilce, 1987; Jorm, 1981).

The basic findings from Share's first experiment—with targets appearing in short texts—were replicated and extended to the English language by Cunningham *et al.* (2002). Using the same procedure and materials adapted from Hebrew to English with targets appearing 6 times in each story, overall decoding accuracy for these second graders was 74%. Replicating Share (1999, Experiment 1), the original target spellings were correctly recognized more often, reproduced with greater accuracy and named more rapidly than homophonic foils.

Confirming a key prediction of the self-teaching hypothesis, Cunningham *et al.* reported a significant correlation ($r = .52$) between orthographic learning and the number of target words correctly decoded during story reading. Kyte and Johnson (2006) also reported a significant positive correlation (.40) between target decoding in their read-aloud condition and their orthographic learning composite (combining spelling, orthographic choice, and naming) for their fifth and sixth graders. It should be kept in mind, however, that target decoding accuracy was at near-ceiling levels (averaging 95%) in these older more proficient readers. In a later study by Cunningham (2006) among first graders, the correlation was .66. To complete the picture, Share (2007) found a correlation of .43 between Hebrew target word decoding (which averaged 89% in his Grade 3 sample) and a composite measure of orthographic learning (orthographic choice and spelling), which remained significant (.31) even after controlling for age, general intelligence, and two measures of phonological recoding ability (pseudoword naming and Olson's phonological choice). This latter finding is especially important as it shows that these decoding-orthographic learning correlations do not merely reflect a general association between decoding and orthographic skills but an item-specific relationship as specified by the self-teaching hypothesis.

1. Orthographic Learning is Rapid and Durable

The evidence reviewed thus far suggests that orthographic learning is both rapid and highly robust. Only a few exposures seem sufficient to produce detectable orthographic learning; indeed, four exposures have been shown to produce reliable outcomes in a number of studies (Ehri & Saltmarsh, 1995; Reitsma, 1983a, 1989; Share, 1999), three exposures too (Hogaboam & Perfetti, 1978), but results for two exposures are mixed (Reitsma, 1983a, 1983b, 1989). These data suggest a "threshold" model of orthographic learning with significant learning occurring only after some threshold level of experience. In contrast, connectionist models (e.g., Harm & Seidenberg, 1999, 2004; Plaut *et al.*, 1996; Woollams *et al.*, 2007) as well as more general instance-based learning theories (e.g., Logan, 1988) predict significant learning from the very first trial; indeed the standard connectionist learning algorithm (the delta rule) predicts that the most "powerful" learning trial is necessarily the first trial owing to the fact that changes in connection weights are directly proportional to the magnitude of the discrepancy between the current (initial) values and target values.

The tantalizing possibility that a single learning trial is sufficient to produce significant orthographic learning was investigated by Share (2004). In this study targets were presented (again in meaningful text) either once, twice, or four times. This study also pursued the question of durability by comparing orthographic learning after 3, 7, and 30 days. According to Hogaboam and Perfetti (1978), orthographic learning is maintained for at least 10 weeks! Hebrew-speaking third graders participated in a fully crossed 3 (exposures) by 3 (post-test intervals) design. Even a single exposure produced significant post-test learning, with 61% success spelling the critical (homophonic) letters where chance is 50%, $z = 3.30$. And remarkably, this newly acquired orthographic knowledge was retained for up to 30 days after exposure (collapsing across all 3 exposures)—59%, $z = 2.66$. The orthographic choice data reproduced this pattern of outcomes. There was a small but non-significant 16 ms advantage in naming latencies for targets compared to homophones.

These data clearly support the item-specific logistic learning functions posited by the connectionist models. Furthermore, they subsume the printed word-learning data within the broader context of skill learning as discussed previously (Logan, 1988, 2002; Newell & Rosenbloom, 1981).

Nation, Angells, and Castles (2007) also addressed the question of rapidity and durability of orthographic learning in their (Year 3 and Year 4) English-speaking sample. Of special interest here was their attempt to replicate the single-exposure finding of Share (2004, Experiment 1). Their study compared 1, 2, and 4 exposures and evaluated retention after 1 or 7 days. Pseudoword targets were presented for oral reading either in story context or without context: overall decoding accuracy averaged 78%. Orthographic choice was the sole measure of orthographic learning. Outcomes indicated superior recognition at the 1-day delay compared to the 7-day delay, and 4 exposures was superior to a single exposure (with intermediate outcomes at 2 exposures). Of primary interest here are the findings for single-exposure learning. Although the overall result was (just) significantly beyond the 25% chance level, it is apparent from Table I (Nation *et al.*, 2007, p. 76) that only the 1-day result (41%) but not the 7-day outcome (30%) was beyond chance (25%) performance. This result raises doubts about the reliability of single-trial orthographic learning.

Nation *et al.*, like others, found significant albeit modest correlations (.38, 1-day; .28, 7-day) between target decoding accuracy and orthographic learning among these Year 3 and Year 4 children. Examining the relation at the item level, Nation *et al.* used logistic regression to show that orthographic learning was greater for items decoded correctly, at both the 1- and 7-day interval. In contrast, a within-item regression showed no effect of decoding accuracy on orthographic choice at 1 day and a marginal effect at 7 days. It is important to note, however, that the dependent measure was not a continuous variable but a forced choice between four alternative spellings with chance performance expected to average 25%. Whereas performance on orthographic choice for correctly decoded items was clearly well above chance (51%; 1-day, and 43%; 7-day)—indicating reliable orthographic learning—performance on targets decoded incorrectly was just above chance at the 1-day interval—37% ($p = .035$, 1-tailed) and unequivocally at chance (26%) at 7 days. Considering the repeated finding that orthographic learning is not a transitory 1-day phenomenon but a long-lasting effect (over weeks, Bowey & Muller, 2005; Landi *et al.*, 2006, and even months, Hogaboam & Perfetti, 1978; Share, 2004), it seems fair to conclude that the Nation *et al.* data demonstrate reliable orthographic learning only when targets are correctly decoded. And this is surely strong item-level support for the self-teaching hypothesis.

A further point needs to be made here too. As already emphasized previously, the self-teaching hypothesis argues that successful decoding does not guarantee orthographic learning—but only provides opportunities for orthographic learning. Other factors (see the earlier phonology-primary/orthography-secondary section) will also influence the assimilation of new word-specific orthographic information. In remarking that "there were many instances where items were decoded correctly but not recognized ..." Nation *et al.* are misrepresenting the self-teaching hypothesis to imply a perfect one-to-one (and causal) correlation between target decoding and orthographic learning. As emphasized in this chapter and in previous discussions (Jorm & Share, 1983; Share, 1995), decoding is a necessary but not sufficient condition for orthographic learning. It is therefore unreasonable to expect that all targets decoded successfully will result in correct orthographic choices. However, the self-teaching hypothesis clearly predicts significant (i.e., beyond chance) and superior orthographic learning for correctly decoded targets. In a later section on individual differences in orthographic learning, I return to the intriguing question of what else accounts for success in orthographic learning beyond decoding.

2. *Pseudowords and Real Words*

Although pseudowords guarantee that a printed word is visually unfamiliar, there are several reasons why it may by unwise to generalize the results from pseudoword learning to naturalistic reading of real words in connected text. First, the availability of phonological knowledge in the form of well-specified phonological representations may permit "early closure" of the decoding process (consider the word *teleph****) especially if this word is encountered in meaningful (although not necessarily predictive) contexts. This would be expected to reduce decoding exhaustiveness thereby diverting attention from orthographic detail. Offsetting these "orthographic" disadvantages, the availability of spoken forms should help resolve any decoding ambiguities particularly for irregular words (see Tunmer & Chapman, 1998, 2006) leading to fewer word identification failures and improved orthographic learning.

These considerations are maximally applicable to beginning readers, for whom most visually novel words are likely to be familiar in spoken form. Later, of course, an increasing number of new words will also be unfamiliar in spoken form—hence phonological learning will accompany orthographic learning as is the case for pseudowords. In most of the studies discussed previously target words were pseudowords but for the few studies using real words (Ehri & Roberts, 1979; Ehri & Wilce, 1980; Reitsma, 1983a, Experiment 3, 1989) the outcomes for orthographic learning seem indistinguishable from the pseudoword data.

Subsequently, Cunningham (2006) examined orthographic learning of real words in unassisted (oral) reading of connected text in normal first grade English-speakers/readers. Both the original spelling (*piece*) and a pseudo-homophonic spelling (*peece*) were presented. Prior knowledge of the reading accuracy of these items was evaluated on a comparable sample of first graders—only words that 95% of the pilot sample could *not* identify correctly in print were included in the experiment. (It should be noted that, for first grade readers, these items are clearly challenging as regards spelling–sound relationships—*bored*, *chews*, *course*, *groan*, *pause*, *piece*, *prince*, and *thirsty*.). Targets appeared six times either in context (short stories) or in a decontextualized condition (i.e., the same short stories scrambled). There was clear evidence of above-chance orthographic learning on the orthographic choice post-test with similar results for both context and scrambled conditions. The spelling data were less clear although Cunningham noted that this task proved very difficult for these beginner readers/writers.

To summarize, the rapidity and durability of orthographic learning seems to apply to both real and pseudowords, although the underlying processes may not be identical.

3. *Silent and Oral Reading*

Bowey and Muller (2005) raised an important concern regarding prior work using oral reading. Even when a child engages in unassisted oral reading before an adult there is an implicit obligation to read all the text. Truly independent reading is a private activity not performed either in a dyadic or public setting and furthermore silent rather than oral—at least among young readers who are no longer "beginners." Truly silent reading among beginners is questionable (Wright, Sherman, & Jones, 2004) but among older children, from around third grade at least, silent reading is the norm and therefore represents the most "authentic" mode of independent reading.

Accordingly, Bowey and Muller (2005) examined self-teaching during silent reading in a large sample of third graders. Targets (and homophonic foils) were presented either 4 or 8 times with post-test orthographic learning evaluated either immediately or at a 6-day delay. Bowey and Muller elegantly matched the targets and homophones for grapheme–phoneme correspondences by switching component vowel graphemes—(*ferd*/*surn* and *furd*/*sern*). Orthographic learning was evaluated using list-based naming times (target lists versus homophone lists) as well as 3-choice orthographic choice (*furd*/*ferd*/*fard*). Target lists were read faster than non-target lists (with no difference in accuracy), and orthographic choices for the original spelling far outnumbered homophonic foils.

Bowey and Muller argued that the presence of rapid orthographic learning not only in the orthographic choice task but also in the list-reading task indicated that rapid orthographic learning must have involved phonological recoding during silent reading of stories. "Phonological recoding can be inferred most safely when children name target nonwords faster than homophone alternatives. Children can do so only if they have already phonological recoded them within story reading and established functional orthographic representations that amalgamate graphemic and phonological information ... Our finding that target nonwords were read faster than homophones thus provides a strong case for self-teaching through phonological recoding" (p. 218).

In a follow-up study of silent reading with third graders, using immediate and 2-day post-test delays, Bowey and Miller (2007) again found faster list-naming times for targets compared to foils (with no difference in accuracy), but while orthographic choice at immediate delay was highly significant, the 2-day delay effect was only marginal.

De Jong and Share (2007) also found evidence of significant orthographic learning in silent reading in a Dutch study designed to directly compare the two reading modes—oral and silent—in a within-participants design. They predicted superior orthographic learning in oral compared to silent reading owing to the greater involvement of phonological processes in oral reading. Third graders read short texts with target pseudowords appearing either twice or six times: orthographic choice, spelling and naming (vocalization onset latencies for individual items) were evaluated three days later. Replicating Bowey's work, there were significant and similar levels of orthographic learning as assessed by orthographic choice and spelling in both oral and silent reading. An advantage for naming latencies was obtained for targets in oral but not silent reading. De Jong and Share concluded that although there was some evidence for stronger orthographic learning in oral reading, the differences were not profound.

The reader may recall that Reitsma's (1983a) very first study in orthographic learning was a semantic categorization task (in a third grade sample)—a silent reading task in which items appeared six times and that revealed reliable orthographic learning after four trials. Putting all these three studies together makes a good case for self-teaching in silent reading.

C. INDIVIDUAL DIFFERENCES IN SELF-TEACHING, DYSLEXICS, AND OTHER POOR READERS

As with the enormous variability in acquired skills such as reading, orthographic learning also encompasses profound individual differences. Although some children just keep decoding new words laboriously over and over as if seen anew for the first time, for others orthographic learning seems virtually instantaneous—the switch from effortful phonological recoding to seemingly direct orthographically-based retrieval appears to occur in a single encounter.

Because cultural tools such as reading lack a dedicated brain basis anchored in evolution, the topic of individual differences is probably as important as the "normative" architecture of the system. Perhaps for this reason, in almost all research in this field—from the earliest pioneering efforts through to contemporary studies—the issue of individual variability has been high on the agenda. This question has been pursued in a variety of research designs including group-wise comparisons of high- and low-ability readers (or diagnosed dyslexics) as well as correlational approaches examining the full spectrum of variability.

Turning first to comparisons between designated groups of good and poor (or dyslexic) readers, Hogaboam and Perfetti's (1978) second experiment found significant orthographic learning but no group-by-condition interactions when comparing above-average Grade 4 readers to below-average readers. The same result emerged in Reitsma's (1983a, Experiment 3) study of first graders split into more- and less-skilled sub-groups which found significant overall orthographic learning but no group interactions. In contrast, the findings for disabled readers tell a very different story. Reitsma also included an older group of third grade disabled readers (diagnosed dyslexics) who were matched to the first graders. Among these disabled readers, he found no evidence of orthographic learning (even after 6 exposures) either in naming speed or accuracy, although sensitivity to word-specific information was evident in a set of very high-frequency words that were read significantly faster than their corresponding homophonic (mis)spellings. In the later studies summarized by Reitsma (1989) using 6 (Experiment 1) and 18 exposures (Experiment 2), disabled readers (but not normal readers) once again showed no evidence of orthographic learning.

A similar result for disabled readers was also obtained by Manis (1985). By the third training session (after six visual exposures), naming times (and errors) for the normal readers (but not the disabled readers) had converged on the naming times for a set of high-frequency control words. Error and latency data clearly indicated that learning had occurred among the disabled-reader group, but not at the same pace as the normal readers. As in Reitsma's work, which found evidence of orthographic knowledge for familiar (high-frequency) words, it seems fair to conclude that orthographic learning among disabled readers is not entirely absent but much slower or less efficient. To date, no study has yet pursued the issue of how many exposures (or the type and context of exposure) are required for disabled readers to demonstrate reliable orthographic learning of the type that occurs so rapidly among most readers.

Further evidence for deficient orthographic learning by disabled readers was reported by Ehri and Saltmarsh (1995) who taught skilled and less-skilled first graders and older disabled readers to read simplified phonetic spellings for a set of real words (e.g., *mesngr*, *stupd*). Following Reitsma (1983a), original and altered spellings were presented in a naming task 3 days later. Altered spellings included both phonetic equivalents (e.g., *cradl/kradl*) and phonetically close but non-equivalent spellings (e.g., *bambu/pambu, stupd/stup*). All target spellings were directly taught by the experimenter who also explained the meaning of each word. The test list was then practiced between 10 and 12 times over consecutive days, with all mispronunciations corrected and reread. Skilled first grade readers required only four practice trials to achieve errorless performance on the entire list, but the other two groups each required over twice this number of trials. Three days later, both non-disabled groups, but not the older disabled readers, read the original spellings significantly faster than the fully homophonic spellings. For phonetically divergent spellings, all three groups were significantly faster on the original spellings.

All these data are consistent with the self-teaching hypothesis, which holds that poor decoding skill should impair orthographic learning. Hence disabled readers who, as a group, have well-known decoding deficits, would be expected to demonstrate inferior orthographic learning. In contrast, it is often claimed that disabled readers have "compensatory" abilities in non-phonological aspects of reading such as visual-orthographic skills. Supporting the notion of compensatory processing is the common finding that orthographic knowledge is often less impaired (relative to reading age-matched controls) than phonological skills—primarily pseudoword naming (see Share, 1995 for a review). If this is more than just a reflection of greater print exposure among the older more experienced readers and constitutes an acquired processing strategy, then orthographic learning tested in an experimental paradigm in which print exposure is a constant should be better than expected on the basis of decoding ability alone.

This compensatory hypothesis (and several related issues) were examined in a study by Share and Shalev (2004) comparing the self-teaching of four groups of children: dyslexics in Grades 4, 5, and 6, non-dyslexic garden-variety poor readers, age-matched normal readers, and a younger group of normal readers matched to the garden-variety poor readers on both reading *and* mental age. Decoding deficits were expected to impair identification of target words leading to inferior orthographic learning, but, if the compensatory hypothesis is correct, disabled readers' orthographic learning was predicted be somewhat *less* impaired than non-disabled readers. Consistent with their pre-existing levels of reading ability, target decoding levels were highest for the non-disabled (normal) readers, lowest for the dyslexics with the garden-variety sandwiched in between (see Figure 1).

Contrary to the English and Dutch data, however, the Hebrew data revealed lower but reliable levels of orthographic choice and spelling among the disabled readers that were closely tied to levels of target decoding (see the three near-parallel lines in Figure 1). A non-significant repeated

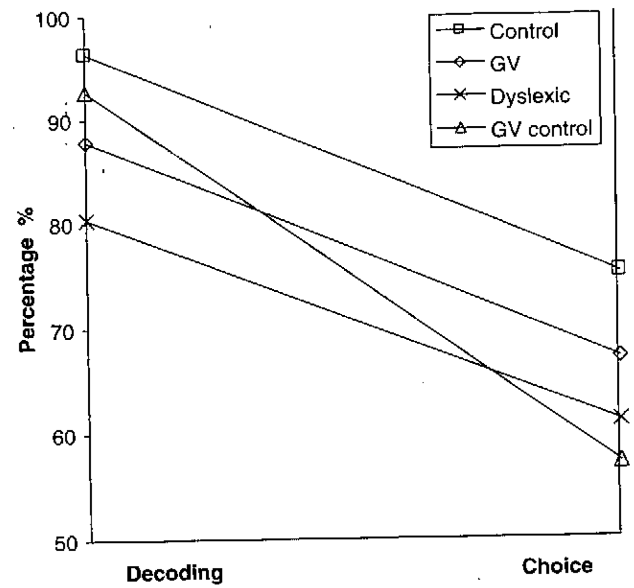

Fig. 1. *Target decoding and orthographic choice (in percentages) in four groups of readers [chronological level (CA)] controls, garden-variety poor readers, dyslexics, and garden-variety [reading level-mental age (RL-MA)] controls (reprinted with permission from Share & Shalev, 2004).*

measures group-by-measures interaction confirmed the parallelism portrayed in Figure 1. Even the main effect of group on both target decoding and orthographic learning vanished after overall reading level was controlled, thereby confirming the picture of developmental delay rather than deviance. (The highly divergent result for the younger reading-age-matched group is discussed subsequently in the section on *early onset*.) Outcomes also indicated that IQ-discrepant and non-discrepant poor readers differed quantitatively but not qualitatively. This remarkably close match between overall (group-wise) levels of target decoding and orthographic learning reinforces the experimentally induced differences reported in Share (1999) and also Kyte and Johnson (2006).

As regards the "compensatory processing" hypothesis, there was no hint of evidence that either group of poor readers was able to compensate for poor decoding via "superior" orthographic skills. Experiential factors such as print exposure rather than inherent or cultivated processing skills may be the source of the orthographic "advantage" enjoyed by poor readers in reading-age comparisons.

The next group of studies examined the individual-difference issue from a somewhat different angle: each was specifically motivated by the self-teaching hypothesis and each used a correlational or regression-based approach surveying the full range of ability rather than selected groups or sub-groups differing in overall reading ability.

The first study exploring variability in orthographic learning was Cunningham *et al.* (2002). In addition to the significant correlation ($r = .52$) already mentioned between second graders' target decoding and composite orthographic learning, Woodcock Word Attack skills also correlated .58 with orthographic learning. Rapid serial naming (RAN) correlated weakly (.35) but not general cognitive ability (Raven, Peabody and digit-span). Hierarchical regression also established that after target decoding accuracy was partialled out, neither cognitive ability nor RAN contributed additional unique variance to orthographic learning. Orthographic knowledge (Olson's spelling choice test), in contrast, contributed a significant and substantial 20% of variance.

Cunningham (2006) also examined sources of variability in orthographic learning in her study of first graders: predictors included rapid naming, general cognitive ability, and orthographic knowledge (a composite of spelling choice—*take-taik*, homophone choice—*Which is a flower*; *rows/rose*, and wordlikeness—*Which looks most like a word*; *fage/fayj*). Simple correlations with orthographic learning were again found for Woodcock Word Attack but not RAN or general intelligence. Prior orthographic knowledge again accounted for additional unique variance in orthographic learning (11%) after the contribution of target decoding accuracy, but not rapid naming or general cognitive ability.

In their study of self-teaching in silent reading, Bowey and Miller (2007) sought to evaluate Cunningham *et al.*'s (2002) individual-difference findings. Using a similar set of predictors, this study examined variability in orthographic learning (assessed by orthographic choice alone) immediately following exposure and again after a 2-day interval. As noted earlier, the relevant orthographic choice outcomes were highly significant at the immediate post-test, but the data for the 2-day delay were inconclusive—a finding at variance with almost all the studies reviewed here and one that places a question mark over the dependent variable.

Turning to the results, Bowey and Muller found a significant correlation (.42) between general phonological recoding efficiency (pseudoword naming accuracy and speed combined) and orthographic choice, but no evidence for a relation between rapid naming and orthographic learning—a purely accuracy measure in this study. A significant but weak (.30) association between orthographic knowledge and orthographic learning was also obtained, but after partialling out general phonological recoding efficiency, orthographic knowledge only explained a marginal 6% of the variance. A similar re-analysis of Cunningham *et al.*'s data (controlling for Word

Attack) also revealed a weak and marginal association between orthographic knowledge and orthographic learning.

The contribution of RAN to orthographic learning was also evaluated in a study of the role of decoding fluency in orthographic learning by Lurie and Share (2007) presented in fuller detail subsequently. This study examined the relations between several phonological processing tasks (RAN included), target decoding accuracy and speed, and orthographic learning (a composite of spelling production and orthographic choice) in a sample of Hebrew-speaking third graders. Instead of the conventional RAN, which usually requires RAN of single digits and letters (and sometimes pictured objects and colors), this study presented sub-syllabic CV units for rapid naming—combinations of consonantal letter and appended vowel diacritic that are the basic building blocks of printed Hebrew words (see Share & Blum, 2005). Whereas non-RAN tasks such as pseudoword repetition (accuracy) correlated more with target decoding accuracy than target decoding speed, Lurie and Share's RAN measure correlated more with decoding speed than accuracy.

Turning to the decoding-orthographic learning relation, the RAN task correlated significantly with orthographic learning and, furthermore, this relation was sustained even after partialling out target decoding *accuracy*. However, when target decoding *speed* was partialled out, the RAN measure was no longer significant, indicating that the RAN task contributes to orthographic learning via its contribution to decoding speed. This finding supports the view that RAN contributes unique variance to orthographic learning (Bowers & Wolf, 1993), but suggests that this contribution derives not from non-phonological sources of variance but from the speed dimension of phonological processing not tapped in traditional un-timed measures of phonological processing. The Lurie and Share data affirm that for self-teaching to operate effectively, the constituent elements of novel letter strings must not only be decoded accurately but also sufficiently fast for the establishment of word-specific orthographic representations.

Share (2007) followed up the Cunningham *et al.* (2002) study with a wide-ranging battery of predictors aimed at comparing sources of individual differences in orthographic learning in two scripts—shallow pointed Hebrew and the relatively deeper unpointed script. One of the aims of this study was to test the phonology-primary/orthography-secondary hypothesis outlined previously. In addition to multiple measures of phonology and orthography, potential predictors of orthographic learning included general intelligence, working memory, cognitive style (Kagan's test of reflection-impulsivity—the Matching Familiar Figures Test), morphological knowledge, semantics, and syntax. Eighty third graders proficient in reading both pointed and unpointed text read a series of short passages (half pointed, half unpointed) each containing a target pseudoword appearing four times. Post-test measures (orthographic choice and spelling production) were administered one week later.

Levels of consonantal decoding accuracy for the two types of targets (pointed and unpointed) as well as post-test orthographic choice and spelling were very similar. To test the phonology-primary/orthography-secondary hypothesis, hierarchical regression was employed by first entering age and general intelligence followed by a block of phonological variables (pseudoword naming accuracy, time-limited phonological choice, target decoding accuracy, phonological awareness, and oral pseudoword repetition) and a block of orthographic variables (Olson's orthographic choice, Kleiman's time-limited word boundaries measure, WISC-III Symbol Search, and Stanford-Binet Bead Memory) each entered, in turn, at Steps 2 and 3 (see Figure 2). As can be seen in Figure 2, two mirror images emerged; the phonological block was the strongest predictor of orthographic learning in shallow pointed script (see the middle segment of the leftmost column labeled with the variance figure of 19%), but the visual-orthographic block the foremost predictor of unpointed orthographic learning—the middle segment (20%) of the rightmost column. Thus, the phonology-primary/orthography-secondary hypothesis was upheld in the case of Hebrew's highly regular fully voweled (pointed) orthography, but rejected for the deeper unpointed text.

Replicating the findings of Cunningham (Cunningham, 2006; Cunningham *et al.*, 2002) and Bowey and Miller (2007), conventional RAN digits and letters did not contribute reliably to orthographic learning, nor did meaning or syntax although it should be kept in mind that all targets were pseudowords. On the positive side, there was evidence for a role of working memory and cognitive style (reflectiveness–impulsiveness).

An interesting sidelight in this individual-difference study was the examination of predictors of target decoding accuracy. Consistent with the orthographic depth hypothesis (Frost, 2005; Katz & Frost, 1992), the pronunciation of pointed pseudoword targets in text was associated only with sub-lexical phonology and working memory, whereas the decoding of the deeper unpointed targets was related to a wide range of sub-lexical, lexical, and supra-lexical factors (phonology, working memory, visual-orthographic processing, morphology, semantics, and syntax).

Summing up, evidence from multiple independent studies converges in showing that differences between readers in orthographic learning, as posited by the self-teaching hypothesis, are partly dependent on the success of phonological recoding. Beyond this, some intriguing findings have been uncovered but the search for sources of variability in orthographic learning

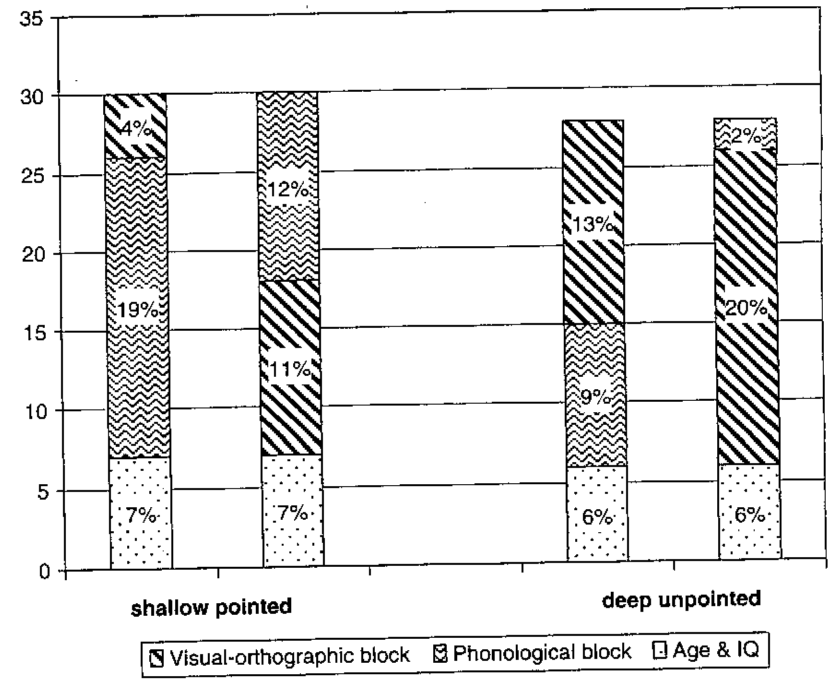

Fig. 2. Variance (R^2 change) in shallow pointed and deep unpointed orthographic learning explained by phonological and visual-orthographic variables (after controlling (Step 1) for age and general intelligence). In each tri-partite column, the first segment represents the variance accounted for by age and IQ (Step 1), the second (i.e., middle segment) is the variance attributable to the block of variables (either phonological or visual-orthographic) entered at Step 2, and the topmost segment the third and remaining block's Step 3 variance.

has clearly only just begun and, like the whole question of orthographic "processing" or "ability," is still largely a black box. Ultimately, there will surely be developmental and script-dependent differences.

D. EARLY ONSET

How early does self-teaching begin? Indirect support for the early onset hypothesis can be seen in the fact that even beginning readers display a certain level of word-specific knowledge. For example, Reitsma (1983b, Experiment 3) found that spellings of familiar words were read faster than homophonic spellings. And there is even evidence for knowledge of general orthographic conventions (Cassar & Treiman, 1997;

Pacton *et al.*, 2001) in that even beginners can recognize illegal spellings such as *ckat*, *mmom*.

As regards the early *acquisition* of orthographic knowledge, Reitsma (1983a, Experiment 3) found significant orthographic learning (manifest in naming times) among first grade Dutch readers after only four exposures. In the first study reported in his 1989 chapter, Reitsma again found significant learning among first graders (even at 2 exposures); the second study found learning among first graders but only after 9 exposures. Three studies by Ehri and coworkers (Ehri & Roberts, 1979; Ehri & Saltmarsh, 1995; Ehri & Wilce, 1980) also obtained reliable orthographic learning among first grade English readers. As discussed previously, however, all these studies either taught children the target words or corrected any misreadings—often asking children to repeat the correct pronunciation—something foreign to independent reading.

Share (2004, Experiments 2 and 3) examined the issue of self-teaching in beginning readers' *unassisted* (oral) reading of Hebrew's highly regular pointed Hebrew. At the outset it needs to be stressed that pointed Hebrew, in contrast to the moderately regular Dutch spelling, is perfectly regular as far as grapheme–phoneme correspondence is concerned. Hebrew also has a relatively simple syllable structure with mostly open CV syllables and few consonant clusters.

Share's Grade 1 study employed a fully repeated-measures design with two and four exposures and 3-day and 7-day post-test intervals. Consonantal decoding of the pseudoword targets was quite accurate (93%). Nevertheless, there was a surprisingly uniform lack of evidence for reliable orthographic learning—all three measures, spelling, naming, and orthographic choice were close to chance.

It must be acknowledged that these findings were derived entirely from pseudoword stimuli, whereas the English and Dutch studies employed real words or pseudohomophones of real words judged to be familiar to children in spoken but not written form. A second study therefore used both types of items, increasing the number of target exposures to 4 and 8 (Share, 2004, Experiment 3). All post-testing was conducted after an interval of seven days. The real words selected to be familiar in spoken but not printed form included words ranging in length from two to four syllables (3–6 consonant letters). The spelling data were consistently at chance and the orthographic choice data (a composite of spelling and orthographic choice) revealed only "glimmerings" of orthographic learning with some results marginally significant, others non-significant.

Additional independent findings from the Share and Shalev (2004) study of self-teaching among older disabled readers corroborated this unexpected result. These data were collected from a group of 20 children tested early in their second school year (Grade 2) who were selected as reading-level controls for older disabled readers. Normal Grade 2 readers were matched to the older readers on speed and accuracy of reading both real words and pseudowords. These young Grade 2 readers decoded the targets at the same level of accuracy as did the Share (2004) Grade 1 children (93%), yet orthographic choices failed to exceed chance levels (57%). No effects were found on either naming accuracy or naming times, and target letter spelling was also very close to chance (52%) (witness the egregiously non-parallel line in Figure 1). Note, however, that all other groups in the Share and Shalev (2004) study demonstrated reliable and significant orthographic learning despite the fact that decoding accuracy was somewhat lower (80% for dyslexics and 88% for garden-variety poor readers). The presence of statistically significant crossover interactions between decoding success, on the one hand, and orthographic choice and spelling on the other, confirmed that these normal Grade 2 readers were unable to recognize or recall orthographic detail despite high levels of decoding success.

Taken together, these three data sets suggest that the early onset hypothesis must be rejected in Hebrew's highly regular pointed script. The evidence of rapid early orthographic learning reported in the deeper orthographies of Dutch and English does not appear to generalize to the shallow pointed Hebrew script. Share and Shalev (2004) advanced two alternative hypotheses to account for the negligible orthographic learning among Hebrew first graders. First, it was suggested that the near-perfect one-to-one letter–sound relations in Hebrew may induce a highly "bottom-up" letter-by-letter ("surface") decoding strategy which is relatively insensitive to higher-order word-level orthographic information. Consistent with this possibility, readers of highly regular orthographies such as Italian and German are often reported to display more exhaustive letter-by-letter decoding (Landerl, 2000; Thaler *et al.*, 2004; Thorstad, 1991)—an observation supported by eye-movement studies (e.g., De Luca *et al.*, 2002; Hutzler & Wimmer, 2004) and brain imaging work (Paulesu *et al.*, 2000). Further supporting evidence comes from a variety of findings reviewed by Ziegler and Goswami (2005) indicating that relative to readers of more transparent orthographies, beginning readers of English are more sensitive to higher-order (larger "grain size") information—at the level of letter patterns and whole words. The orthographic depth hypothesis (Frost, 2005; Katz & Frost, 1992) also asserts that English's deep orthography obliges the reader to look beyond low-level phonology and consider higher-order regularities that are often word-specific.

A second related explanation for the unexpected divergence of the Hebrew findings relates to the often-neglected dimension of decoding *speed* and *efficiency*. The characteristically laborious, letter-by-letter decoding reported among beginning readers of shallow orthographies may simply be too slow to support orthographic learning.

The role of decoding fluency as a contributor to orthographic learning over and above decoding accuracy was directly addressed in a study by Lurie and Share (2007). In a sample of 42 third grade Hebrew readers, accuracy of (pseudoword) target decoding correlated only weakly with orthographic learning ($r = .24$), but decoding times as measured from target presentation onset through to pronunciation *offset* were much more strongly (and significantly) related to orthographic learning ($r = .52$). This finding coheres with a large number of studies indicating that reading *speed* rather than accuracy (which reaches ceiling levels very early in regular orthographies) is a more potent discriminator of developmental and individual differences in regular orthographies (de Jong & van der Leij, 2003; Wimmer, 1993).

This study also examined the relation between decoding speed and orthographic learning in light of the evidence showing that the phonological store (i.e., "phonological loop") in working memory is time-limited, specifically, that memory span is limited to the number of items that subjects can articulate in a 2-second time window (Baddeley, Thomson, & Buchanan, 1975; Naveh-Benjamin & Ayres, 1986; Standing *et al.*, 1980). Consistent with the 2-second notion, children who took longer than approximately 2 s (from target presentation until completion—offset—of pronunciation) displayed significantly poorer orthographic learning, as seen in Table I. By splitting the sample according to the overall naming times

Table I

Orthographic Learning for Children with Overall Naming Times (Onset Time + Naming Duration) above and below Specified Cutoff Points

Naming time (duration) of target words (in seconds)	*n* at or above cutting point	*n* below cutting point	*p* value (spelling production)	*p* value (orthographic choice)
1.8	6	34	.9688	.6991
1.9	11	29	.3020	.1420
2.0	11	29	.3020	.1420
2.1	13	27	.1524	.0573
2.12	13	27	.1524	.0573
2.13	13	27	.1524	.0573
2.14	14	26	.0741	.0322
2.15	14	26	.0741	.0322
2.16	14	26	.0741	.0322
2.17	14	26	.0741	.0322
2.18	14	26	.0741	.0322
2.19	14	26	.0741	.0322
2.2	15	25	.0218	.0095

(leftmost column) it can be seen that only at a cutoff of 2.14 s was there a significant difference in orthographic choice between groups whose average naming times fell either above or below this value. For spelling, this "critical" point was located at a similar value of 2.2 s.

These data support the hypothesis that slow laborious letter-by-letter decoding characteristic of novice readers of shallow orthographies may impair orthographic learning in the same way that slow word recognition can impair text integration processes (Perfetti, 1985). If correct, this decoding fluency hypothesis would explain the lack of orthographic learning among novices.

E. OTHER SELF-TEACHING MECHANISMS?

1. Context

Ever since Goodman's, controversial pioneering study in 1967, the role of context in word identification and word learning has remained disputations. Contemporary investigations of the role of context in orthographic learning continue this tradition.

The early study by Ehri and Roberts (1979) found that learning new printed words in context reduced memory for word-specific orthographic detail compared to an isolation condition. The context-trained group was better at identifying the target words' meanings but acquired less word-specific orthographic detail; the isolation-trained group, in contrast, displayed superior word-specific orthographic knowledge revealed in faster naming times, superior pre- to post-test gains in spelling choice, and letter-level spelling production. A follow-up study by Ehri and Wilce (1980) extended these findings to context-dependent function words (e.g., *might, while, must, from, enough*). The context effect was found to be stronger among the poorer readers (see also Landi *et al.*, 2006).

Archer and Bryant (2001) selected a set of words that first grade children had difficulty decoding (in a list of isolated words). Half of these items were then presented in context (a short meaningful sentence) and half in isolation (the experimenter supplying the pronunciation for items not successfully read alone). Next, the items were re-presented in the original word list, and again a day later. Although children were more successful reading the words in context than in isolation, the experience of words in meaningful context and in isolation led to equivalent improvements in later reading.

Unlike the previous studies, Cunningham (2006) examined the role of context in unassisted reading of target words selected to be familiar in spoken but not printed form. Once again, context helped (English) first graders to decode these items (84% in context versus 67% in context-scrambled condition) but no advantage emerged in post-test orthographic learning. It is important to note however, that the targets were also selected not only on the basis of novelty but also decoding difficulty—all had irregular or complex spellings (e.g., *piece*, *thirsty*). Hence for first graders, context might be expected to assume a greater role relative to less regular words. (Lacking is a study comparing the role of context for regular and irregular words.)

Landi *et al.* (2006) also reasoned that learning new words in a meaningful context draws attention away from orthographic detail—detracting from long-term retention. Their first experiment compared more- and less-skilled first and second graders' orthographic learning as a function of context and isolation. Following Archer and Bryant (2001), Landi *et al.* selected words children were unable to read correctly in isolation. Half were assigned to a context condition and half to an isolation condition. Context consisted of two-sentence paragraphs read aloud by the experimenter. Reading of the target word (presented once only) was unassisted and no feedback provided. A week later, children were asked to read the words aloud (in isolation). Words were read more successfully when presented in context but there was no overall difference in overall post-test reading accuracy. This implies (as was confirmed) that of the words correctly identified at initial exposure, a *lower* proportion of the words identified correctly in context (69%) than in isolation (47%) were retained a week later. Similar effects were obtained for both more- and less-skilled readers. A second experiment replicated and extended these results to a larger sample of children using three presentations of each target word appearing either in isolation, in a single passage or in multiple passages. Although presenting targets in a single context (three times) or in (three) multiple contexts did not alter the outcomes, the context effect was significantly greater for the less-skilled readers as found by Ehri and Wilce (1980).

Martin-Chang, Levy, and O'Neill (2007) threw a spanner in the works by arguing that in all these studies the measurement of practice and retention are confounded. Words practiced and post-tested in isolation had been recalled under the same conditions, context-trained words were test under different conditions (i.e., transfer from context to isolation). In their study, difficult-to-decode words were trained either in context or in isolation, followed by a retention task administered again 8 days later in which trained items were presented under the *same* conditions—isolation or context respectively—as well as a transfer task (trained words presented again in a novel story). Second graders taught via whole-language methods practiced reading test words (with assistance) in isolation or story context

over the course of 3 days.[10] Words were read more accurately in context than isolation and this advantage was maintained at the 8-day post-test (keep in mind that context-trained items were tested in context, isolation-trained items tested in isolation). Reading the test items in a novel passage in the transfer task, context evinced a much larger advantage compared to isolation. Turning the tables, and confirming the authors' "congruency" hypothesis, a second study found a clear advantage at transfer for words practiced *in isolation* when post-test transfer was tested in a novel *isolated* word reading task. Martin-Chang *et al.* concluded that transfer is greatest when congruency of training and transfer is maximized.

Several general comments are pertinent to all these studies. With the exception of Cunningham (2006), the fact that all these studies involved explicit teaching or corrective feedback and practice limits the conclusions that can be drawn regarding unassisted independent reading/self-teaching. As already discussed, this is a genuine problem in English. The use of words selected not on the basis of ascertained unfamiliarity but of demonstrated decoding difficulties is problematic from the point of view of the self-teaching hypothesis—these items may be creating problems for reasons such as spelling complexity or sheer length, thereby necessitating greater than usual reliance on context (see Share, 1995; Tunmer & Chapman, 1998, 2006). It is important to consider various levels of word complexity but in order to reach generalizable conclusions regarding orthographic *learning* it is paramount that researchers ensure that test items are unfamiliar. Experimenter-supplied context or shared reading techniques may be valuable pedagogical tools but are divorced from unassisted everyday reading. Stanovich (1986) drew an important distinction between "effective" context (the context actually gained from unassisted reading) and "nominal" context (the maximum possible contextual support). Also crucial is the level of predictability of the sentences or passages which, in several of these studies, is often far beyond the norm for connected text (e.g., Archer & Bryant, 2001; Landi *et al.*, 2006). Natural text has very low predictability (Share, 1995). Yet another complication is the instructional regime that children have experienced. The Martin-Chang *et al.* sample was recruited from whole-language schools where primary emphasis is placed on contextual prediction rather than decoding skills.

[10] It should be remarked that the training set in this particular study was rather different from the items used in the studies described previously. A total of 85 words (selection criteria unspecified) were embedded in a single story—each appearing twice. Many of this pool would appear to be highly familiar even at this age and also largely regular (e.g., *small, tree, seen, help, caught, looked, screeching, firecrackers*).

Traditional phonics-emphasis instruction might not necessarily yield the same result.

These reservations notwithstanding, results from all these investigations agree that contextual support for identifying hard-to-decode words is helped by context but at the expense of attention to orthographic detail. Hence, when only the print is available on a later encounter, reading suffers. This conclusion also accords with earlier work by Samuels and colleagues (Samuels, 1967; Singer, Samuels, & Spiroff, 1974) on the role of illustrations in printed word learning. "Picture and context cues deter acquisition of reading responses because they enable the child to identify the word in practice without focusing on its graphic features" (Singer *et al.*, 1974, p. 555).

The Martin-Chang *et al.* (2007) study raises an important concern—to which context do we wish to generalize the findings of printed word learning or, for that matter, word training studies? Meaningful text is indisputably the most common context in which new words are first encountered and subsequently read, and, of course, the most important context for expanding knowledge of word meaning and syntactic function (Ehri & Roberts, 1979; Ehri & Wilce, 1980), especially as children encounter more and more words beyond their spoken vocabularies. Ultimately, however, we want children to be able to read and understand words in all possible circumstances—this includes both context *and* isolation. But we want readers who are writers too—so spelling facility is also a crucial element of word learning. Here context is of no consequence. (It is noteworthy that many word-learning studies rely solely on oral reading accuracy—or reading speed—ignoring orthographic knowledge *per se.*) It seems that reading hard-to-decode words with contextual support is likely to perpetuate a level of contextual reliance suitable for text reading that may be detrimental to decontextualized reading and to spelling and writing (consider the case of the good reader—poor speller; Frith, 1980).

The flip side of the argument that context detracts from attention to orthographic detail is, of course, the case of spelling which obliges close and thorough attention to orthographic detail and sub-lexical print-to-sound correspondence—possibly even more than does decoding.

2. *Spelling*

Although a number of studies have demonstrated the beneficial influence of spelling on reading and printed word learning, Shahar-Yames and Share (2008) noted that this evidence could be interpreted simply in terms of the general benefits of superior working knowledge of the alphabetic code

among children still learning the rudiments of print-to-sound decoding rather than word-specific *orthographic* knowledge of the kind on which automatized skilled word recognition depends. In a study focusing specifically on the role of spelling in orthographic learning, Shahar-Yames and Share presented third grade Hebrew speakers with target pseudowords in three conditions; reading, spelling (actually reading-plus-spelling), and an unseen control condition. In the spelling condition, participants first read meaningful sentences containing the target word and were then asked to write down the target from memory with the sentences removed from sight. In this condition each participant read the target twice and wrote the target twice. In the reading-only condition, the participant merely read (decoded) the target (4 times). Post-test orthographic learning was assessed one week later with orthographic choice and spelling production—these two measures were also combined into a composite measure. Spelling was predicted to produce superior orthographic learning compared to reading owing to the additional processing demands invoked, and, furthermore, this advantage was expected to be greatest for later-occurring orthographic detail in view of the fact that spelling obliges the writer to process each and every letter in a word on every occasion whereas decoding encounters, although likely to be quite exhaustive initially, are probably less exhaustive on subsequent occurrences—particularly in connected text.

During the learning phase, similar and high levels of decoding and spelling success were observed in both conditions ensuring that comparison of orthographic learning across the two conditions was not confounded by differences in initial learning. Orthographic learning outcomes are presented in Table II.

Reading led to significant orthographic learning (relative to unseen controls), but spelling led to more powerful and more consistent learning outcomes. The difference between reading and spelling in the case of non-initial letters was almost twice the difference for the initial letter (9.5% versus 5.0%) although formally this interaction failed to reach significance possibly because many of the non-initial letters were not word-final.

Like most "laboratory" training studies, this investigation shows that spelling *can* but not necessarily *does* perform a self-teaching function. The question of applicability to orthographic learning *in vivo* will depend very much on the literacy curriculum and the role of writing as well as factors such as attention to errors, toleration of misspellings, the availability of automatic spelling-correction routines and more. As we saw in the previous section on the contribution of context, the role of spelling in word-specific orthographic learning brings us back to the perennial instructional trade-off between meaning and mechanics.

Table II

Post-Test Orthographic Learning (Means and Standard Deviations in Percentages) across Three Conditions (Control, Reading, Reading/Spelling) with t Values and Effect Sizes (η^2) ($n=45$) (reprinted from Shahar-Yames and Share, 2008)

Post-test measure	Condition: Control M (SD)	Condition: Reading M (SD)	Condition: Spelling M (SD)	Reading/control t	Reading/control η^2	Reading/spelling t	Reading/spelling η^2	Spelling/control t	Spelling/control η^2
Spelling production									
Whole word (%)	22.2 (19.38)	26.1 (19.91)	37.8 (25.35)	.93	.19	2.36*	.11	3.39**	.21
Target letters ($n=2$)	47.8 (14.91)	54.7 (14.67)	61.9 (19.02)	2.05*	.09	2.04*	.09	4.00**	.27
Letter 1	46.7 (23.60)	55.0 (18.92)	60.0 (29.39)	1.80	.07	.99	.02	2.51*	.13
Letter 2	48.9 (20.61)	54.4 (25.16)	63.9 (22.96)	1.08	.03	1.68	.06	3.48**	.22
Orthographic choice (4-choice)	23.9 (21.29)	37.4 (20.61)	41.9 (26.02)	2.82**	.15	.86	.02	3.46**	.21
Composite orthographic learning (z)	−0.79 (1.39)	0.07 (1.68)	0.67 (1.36)	2.67**	.14	2.12*	.09	4.81**	.35

*$p<.05$; **$p<.01$.

IV. Summary, Conclusions, and the Way Ahead

A good deal has been learned about the basic parameters of orthographic learning, but as many researchers in this field have observed (see, e.g., Castles & Nation, 2006; Landi *et al.*, 2006), less is known about *how* this learning comes about. It is encouraging to see that much of this work has offered support to the self-teaching hypothesis. This can be seen in several sets of findings. First, levels of orthographic learning appear to be closely tied to levels of decoding success whether induced experimentally (Kyte & Johnson, 2006; Share, 1999) or occurring naturally (Ehri & Saltmarsh, 1995; Manis, 1985; Reitsma, 1983a, 1989; Share & Shalev, 2004). Second, at the individual level, the data have been quite consistent in showing a significant positive association between target decoding success and orthographic learning—a relation furthermore that does not appear to be simply the offshoot of the general relation between pre-existing decoding ability and orthographic learning (Cunningham, 2006; Cunningham *et al.*, 2002; Kyte & Johnson, 2006; Lurie & Share, 2007; Share, 2007; but see Nation *et al.*, 2007). And third, the role of context in reducing attention to orthographic detail and spelling in enhancing it also confirms the basic self-teaching premise that phonological recoding contributes to orthographic learning by drawing attention to letter detail and word-specific spelling–sound relations.

Much work in this field lies ahead. The orthographic learning function needs to be systematically mapped for both normal and disabled readers. Most studies to date have understandably used a small number of selected points on the learning curve, and although more exposures tend to elicit stronger outcomes, only a comprehensive mapping effort can determine whether orthographic learning adheres to the standard power function common to a wide variety of skill learning. Share's (2004) finding of single-trial learning sorely needs replicating in view of the inconsistencies in Nation *et al.*'s (2007) single-exposure findings. If confirmed, this would establish yet another tie between printed word learning and spoken word learning given the well-known phenomenon of fast mapping in spoken language development (see, e.g., Baldwin & Tomasello, 1998; Carey & Bartlett, 1978; Dollaghan, 1987; Woodward, Markman, & Fitzsimmons, 1994).

Another potentially fruitful avenue for future research emerges from the earlier discussion of the unfamiliar–familiar/novice–expert dualism in which I argued that an efficient orthography must supply the reader not only with a means for identifying novel words—a self-teaching device—but also with visually distinct configurations for morphemes necessary for the unitization and automatization of word recognition. It might be hypothesized that the greater the distinctiveness of individual morphemes (operationalized, e.g., via orthographic neighborhood density or by distinctive graphic features such as capital letters, descenders, or ascenders), the faster and more efficient the unitization process.

Yet another important but untouched topic in the study of orthographic learning is the acquisition of knowledge of general orthographic conventions. To date, all the work referred to in this chapter has dealt exclusively with word-specific knowledge. This is a crucial yet very specific (i.e., minimally productive) type of knowledge relating to individual lexical items (or individual lexical families)—typically root morphemes. More general insights into (highly productive) orthographic conventions concerning grammatical and derivational (typically bound) morphemes is another critical dimension of orthographic learning (see, e.g., Chliounaki & Bryant, 2007) that remains to be investigated from the self-teaching point of view.

Research into the determinants of individual differences in orthographic learning has only just begun. Some intriguing and puzzling findings (such as the evidence against the phonology-primary/orthography-secondary hypothesis in deep unpointed Hebrew) will remain enigmas until further research offers clarification. The early onset findings provide cause for optimism. Conflicting outcomes in English and Hebrew have helped point the way to several fascinating new research directions on the question of decoding fluency, word length, and morphemic distinctiveness.

Studies of context effects showing high levels of word identification success that do not translate into superior orthographic learning as well as the initial Hebrew first grade data indicating negligible orthographic learning despite near-ceiling levels of decoding accuracy all provide a warning to researchers regarding the value of using "gross" decoding accuracy that overlook the *nature* of decoding. The "how" of decoding promises to be a painstaking but crucial avenue for future research. We have mountains of research on decoding yet no fine-grained studies revealing how this takes place for different readers at different levels of development and across diverse orthographies. We need to scrutinize the nature and location of the errors and not rest content with crude measures of overall accuracy. No study has yet gone beyond overall target decoding success and selectively examined errors on the critical homophonic letters. The entire process of decoding remains unchartered waters—is this performed letter-by-letter followed by one-step whole-string blending, maximally "chunked" (i.e., blended at each point along the entire string), or perhaps chunked at some intermediate point such as the sub-syllabic (e.g., onset-rime or body-coda sub-division), or whole syllable level? Does

this process vary by script possibly aligning with the grain sizes postulated by the psycholinguistic grain size theory (Ziegler & Goswami, 2005)? Is the process foreshortened in the case of a phonologically familiar word? Where are the differences between regular and irregular words (and pseudowords) in context and in isolation—might this shed light on how context mediates orthographic learning? Above all, how does the *process* of decoding impinge on the assimilation of orthographic information? It should be apparent that simply recording raw decoding accuracy is merely scratching the surface of one of the most complex (and poorly understood) processes children accomplish.

We know a great deal about the role of phonology in reading acquisition but the nature and origins of ("crystallized") orthographic knowledge and the factors underlying its development (let us call it "fluid" orthographic ability or aptitude) remains a black box (Burt, 2006; Castles & Nation, 2006; Share & Stanovich, 1995; Venezky, 2006). Symptomatic of this lack of progress are the heated debates over the nature and definition of surface-subtypes of acquired and developmental dyslexia (see, e.g., Coltheart, 2005; Woollams *et al.*, 2007) and the ongoing controversy over the role of RAN in reading (see, e.g., Katzir *et al.*, 2008; Vukovic & Siegel, 2006).

The subject of orthographic learning offers researchers a field of study lying at the very heart of one of the most important and challenging skills that children are expected to master. It is a promising young field replete not only with fresh discoveries, enigmatic and contradictory findings but brimming with research questions awaiting investigation.

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DEVELOPMENTAL PERSPECTIVES ON LINKS BETWEEN ATTACHMENT AND AFFECT REGULATION OVER THE LIFESPAN

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In the late 1950's since John Bowlby's initial reflections on infant–caregiver attachment first appeared in print, attachment theory has arguably revolutionized research on affectional bonding and its role in psychological health and development. One of the most compelling aspects of attachment theory is its lifespan perspective. Although Bowlby focused primarily on infant–caregiver attachment, he argued that attachment