HHS Public Access
Author manuscript
Cogn Neuropsychol. Author manuscript; available in PMC 2018 November 16.

Published in final edited form as:
Cogn Neuropsychol. 2017 ; 34(3-4): 65–82. doi:10.1080/02643294.2017.1369016.

Developmental Dysgraphia: An Overview and Framework for Research

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Abstract

Developmental deficits in the acquisition of writing skills (developmental dysgraphias) are common and have significant consequences for those who suffer from them, yet these deficits have received relatively little attention from researchers. In this article we offer a framework for studying developmental dysgraphias (including both spelling and handwriting deficits), arguing that research should be grounded in theories describing normal cognitive writing mechanisms and the acquisition of these mechanisms. We survey the current state of knowledge concerning developmental dysgraphia, discussing potential proximal and distal causes. One conclusion emerging from this discussion is that developmental writing deficits are diverse in their manifestations and causes. We suggest an agenda for research on developmental dysgraphia, and suggest that pursuing this agenda may contribute not only to a better understanding of developmental writing impairment, but also to a better understanding of normal writing mechanisms and their acquisition. Finally, we provide a brief introduction to the subsequent articles in this special issue on developmental dysgraphia.

Keywords

developmental dysgraphia; spelling, handwriting; reading; developmental dyslexia

The ability to write is a fundamental component of literacy, and is crucial for success not only in school but also in most workplace environments. Unfortunately, a significant proportion of children suffer from developmental dysgraphia—that is, impairment in acquisition of writing skills. Döhla & Heim (2016) recently estimated that 7–15% of school-age children exhibit some form of development writing deficit.

In addition to disrupting the acquisition of writing skills, developmental dysgraphia often has broader detrimental effects. For many dysgraphic children any writing assignment is an ordeal; the struggle to spell words correctly or produce legible handwriting is immensely frustrating, and also diverts attention from the more substantive aspects of the assignment (e.g., Berninger, 1999; Graham et al., 1997). A child struggling with spelling while writing a paragraph about frogs will probably learn less about paragraph composition, and about frogs, than a child with typical spelling skills; and a child who struggles to write digits

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legibly and align them neatly will probably work longer and harder at math homework, while learning less, than a child with typical handwriting skill. Nor are the detrimental effects of developmental dysgraphia limited to children. Adults with significant developmental writing deficits may face limitations in career choice or advancement, as well as experiencing difficulty with everyday tasks that draw upon writing skills.

Despite the prevalence and significant impact of developmental dysgraphia, the topic has received relatively little attention from researchers. A major purpose of this special issue is to highlight the need for a strong, sustained program of research. An intensified research effort is crucial not only for advancing our knowledge of the underlying deficits in children and adults with developmental dysgraphia, but also for improving diagnosis and treatment. Furthermore, studies of developmental dysgraphia may enhance our understanding of normal cognitive writing skills and how these skills are acquired.

Writing & Dysgraphia: Defining the Scope

Writing and dysgraphia are both broad concepts, and the corresponding terms have been used in various ways. Hence, it is important at the outset to define the scope of our discussion, and clarify our use of terminology. In discussing writing we focus on production of characters and individual words. Higher-level writing skills, such as those involved in composing sentences and combining them into coherent texts, are beyond the scope of our discussion.

In other respects, however, we define the writing domain broadly. We include within our purview not only writing in print or script with a writing implement, but also other forms of written language production, such as typing on a laptop or texting on a smartphone. We also include both the ability to spell, and the ability to plan and execute the motor processes required to generate an overt output. In the case of handwritten output we refer to the motor planning and production processes as handwriting processes, and include under this rubric both printing and cursive writing.

Turning now to writing impairments, the term *dysgraphia* has two different senses in the literature. Some researchers use the term to refer to impaired spelling, whereas others apply the label to deficits affecting the motor planning or production processes required for handwriting. We include both senses within the scope of our discussion. Finally, by *developmental dysgraphia* we mean impairment in acquisition of writing (spelling, handwriting, or both), despite adequate opportunity to learn, and absence of obvious neuropathology or gross sensory-motor dysfunction.[1]

[1]Dysgraphia (in the sense of impaired spelling) is often included in definitions of developmental dyslexia (see, e.g., the International Dyslexia Association's definition: "Dyslexia . . . . is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities," "Definition of Dyslexia", 2017). The extent to which developmental spelling deficits associate with and dissociate from developmental reading deficits is an important issue for research, and we include within the scope of our discussion developmental dysgraphias occurring either in the presence or absence of reading impairments.

A Theory-Based Approach

We advocate a strongly theory-based, as opposed to descriptive, approach to the study of cognitive deficits, including developmental dysgraphia. We argue that deficits affecting a cognitive function can be understood only by reference to a theory that specifies the normal cognitive representations and processes underlying the function (e.g., Caramazza, 1984; Caramazza & McCloskey, 1988; Castles & Coltheart, 1993; Hillis & Caramazza, 1992; McCloskey & Caramazza, 1988; McCloskey, 2001; McCloskey, Aliminosa, & Macaruso, 1991). Given such a theory, deficits can be characterized in terms of disruption to particular component(s) of the normal cognitive system.

Efforts to understand developmental deficits also require a theoretical framework specifying how the affected cognitive system is learned (Castles, Kohnen, Nickels, & Brock, 2014). Developmental deficits arise from disruption of normal learning processes. Consequently, a theory characterizing the learning processes is crucial for understanding the failures of learning that underlie developmental cognitive impairments. In the domain of writing, theories of learning are currently less well-developed than theories of the normal adult system. Hence, we first describe a theoretical framework specifying the structure and functioning of the normal adult writing system, and illustrate the role of this framework in the study of acquired dysgraphia (writing deficits resulting from brain damage in adulthood). We then consider the processes involved in learning to write, and the potential roles of these processes in the genesis of developmental dysgraphias.

The Normal Adult Writing System

Figures 1 and 2 illustrate a theory of the cognitive mechanisms making up the normal adult writing system. Figure 1 focuses primarily on spelling mechanisms and Figure 2 on the mechanisms for the production of handwriting. The theory illustrated in the figures reflects a consensus (although not universal agreement) among scientists who study writing (e.g., Tainturier & Rapp, 2001; Margolin, 1984; see Graham, 2014, for a different framework). We offer the theory as a set of working assumptions that, while subject to revision in light of new evidence, can serve as a foundation for the study of developmental writing deficits. Note also that the theory assumes an alphabetic writing system. Although some aspects are applicable to non-alphabetic systems, other aspects would require extensive modification to address non-alphabetic writing.

Cognitive Spelling Mechanisms

Figure 1 illustrates cognitive spelling mechanisms in the context of a spelling-to-dictation task in which a word is dictated, and then is written or spelled aloud. The theory assumes that if the dictated stimulus is a familiar word (e.g., CAT), the sequence of phonemes computed by speech recognition processes (e.g., /k æ t/) activates a representation in phonological long-term memory (often referred to as the phonological lexicon), leading in turn to activation of a lexical-semantic representation. (Note that these auditory comprehension processes are not specific to spelling tasks.) The semantic representation in turn activates a stored spelling representation in orthographic long-term memory (also referred to as the orthographic lexicon). Some theorists have proposed that representations in orthographic long-term memory can also be activated directly from the phonological long-term memory (e.g., Margolin, 1984), or by a combination of inputs from phonological long-term memory and lexical semantics (e.g., Hillis & Caramazza, 1991).

The activated orthographic representation specifies the identity and ordering of letters making up the spelling of the word. The letter representations are assumed to be abstract (Rapp & Caramazza, 1997), in the sense that they specify only letter identity and not any aspects of letter form (e.g., the visual shape of a letter, or the strokes for writing it). The abstract orthographic representations provide the basis for producing various forms of output, including writing, oral spelling, and typing. Once activated, the sequence of abstract letter representations is held temporarily in an orthographic working memory (often referred to as the graphemic buffer) while the motor planning and production processes required for generating an overt response are carried out.

Spelling of unfamiliar words or pseudowords (e.g., GRAT) also implicates abstract orthographic representations. However, in this case no lexical-phonological, semantic, or lexical-orthographic representations are available in the lexical system. Instead a plausible spelling is assembled from the input sequence of phonemes (e.g., /g r æ t/), through a sub-lexical spelling process that applies sound-spelling correspondence knowledge. As Treiman (2017) argues, the sublexical process may apply not only simple phoneme-grapheme conversion rules (e.g., /g/ → G), but also more sophisticated context-sensitive rules (e.g., /s/ → C when followed by E, I, or Y). For this reason we refer to the sublexical process as sound-to-spelling conversion process rather than using the more common label of phoneme-grapheme conversion.[2]

Outputs of the sublexical process have the same form as representations of familiar words retrieved from orthographic long-term memory: sequences of abstract letter representations. Like the retrieved representations, spellings generated by the sublexical process are held in orthographic working memory, and production of the overt response proceeds just as for familiar words.

The lexical route, which involves retrieval of a learned spelling for a word, is necessary because (at least for most languages) the correct spelling of a word is not fully predictable from its phonological form. Accordingly, correct spellings cannot reliably be generated through sound-spelling conversion. For example, there is no way to predict from the sounds of the words KEEP and LEAP that the vowel is realized by the letters EE in the former and EA in the latter. Rather the spellings must be memorized (i.e., stored in orthographic long-term memory). Interestingly, studies show that even for languages with highly predictable spellings (e.g., Spanish and Italian) word spellings are learned and stored in orthographic long-term memory (e.g., Cuetos & Labos, 2001; Miceli, Benvegnù, Capasso, & Caramazza, 1997).

[2]Sublexical spelling processes may also draw upon knowledge of morphology (e.g., Treiman, 2017). For example, in English the phoneme sequence /ʌs/ is likely to be spelled OUS when it corresponds to a suffix (as in FAMOUS) but not otherwise (e.g., STATUS, FUNGUS).

The sublexical sound-to-spelling conversion process is needed to generate plausible spellings for words whose spellings have not been learned, including words that have been encountered only in spoken form, and entirely unfamiliar words. For these words, the lexical route cannot supply the correct spelling, forcing reliance on the sublexical route.

A point we have not yet addressed concerns the interaction between the lexical and sublexical routes. One possibility is that the lexical route is first activated, and the sublexical route comes into play only if no stored spelling representation is activated. Perhaps more likely is that the two routes operate in parallel, such that both routes produce an output for familiar words (e.g., Houghton & Zorzi, 2003; Jones, Folk, & Rapp, 2009; Rapp, Epstein & Tainturier, 2002; Tainturier et al., 2013). Under this account any difference between lexical- and sublexical-route outputs would be resolved in favor of the lexical route. For example, if for the word LEAP the lexical route generated the spelling LEAP and the sublexical route produced the output LEEP, the lexical spelling LEAP would be chosen for production.

Although we have introduced the writing theory in the context of a writing-to-dictation task, the theory also applies to the more common situation of spontaneous writing. We assume that in spontaneous writing the writer begins with a message to be conveyed, leading eventually to activation of semantic representations for the to-be-produced words. Activation of spelling representations in orthographic long-term memory, and subsequent processes, are then carried out as for writing to dictation.

For words whose spellings have not been learned, the spontaneous writing process is slightly more complex. Consider, for example, a writer who has encountered the word PLATYPUS only in spoken form, but now wants to write it. After activating the semantic representation, the writer cannot retrieve the spelling from orthographic long-term memory, because the spelling has not been learned. Instead the writer must retrieve the word’s phonological representation from the phonological long-term memory, and then apply sublexical sound-spelling conversion processes to generate a potential spelling (e.g., PLATAPUSS).

Handwriting Processes

Once an orthographic representation has been retrieved from long-term memory or assembled through sound-spelling conversion, additional processing is required to produce an overt response (e.g., Ellis, 1982, 1988; Hollerbach, 1981; Margolin, 1984; van Galen, 1991). First, the abstract letter representations must be converted to a form appropriate for the chosen output format or modality. For handwritten output, letter-form representations (e.g., a representation of lower-case print f) must be activated, whereas for oral spelling letter name representations (e.g., /ɛf/) are required. For other forms of output (e.g., typing) different representations (e.g., keystroke representations) would need to be computed. Here we focus on the processes required for handwritten output.

As illustrated in Figure 2, some theorists (e.g., Ellis, 1982, 1988; Margolin, 1984) assume that in generating a handwritten response, abstract letter representations are first converted to allograph (letter shape) representations corresponding to the chosen form of written output (e.g., lower-case print). The allograph representations in turn activate effector-independent graphic motor plans, which are learned representations specifying the movements (i.e., the sequence of writing strokes) required to write the letter in the chosen form. The graphic motor plans are effector-independent in the sense that they are not tied to particular effectors (e.g., the right hand), and do not specify movements with respect to specific muscles or joints. Hence, the graphic motor plan for upper-case print B could mediate writing of that letter with the right hand, left hand, left foot, or so forth.

Although the assumption of a progression from abstract letter identities to allographs to graphic motor plans is common, some theorists have proposed instead that abstract letter representations are mapped directly to graphic motor plans (e.g., Miozzo & De Bastiani, 2002; Rapp & Caramazza, 1997; Menichelli, Rapp & Semenza, 2008; van Galen, 1991).[3] Regardless of how graphic motor plans are activated, the final steps in the writing process involve the conversion of the graphic motor plans to effector-specific motor programs, and the use of these plans by the motor system to execute the appropriate writing movements with the chosen effector. During the writing process visual feedback plays a significant role, not only in ensuring appropriate orientation and spacing of letters and words across the page, but also in monitoring and controlling the shapes of individual letters (e.g., Danna & Velay, 2015; Smyth & Silvers, 1987).

Theory of Normal Adult Mechanisms and the Study of Deficits

An explicit theory specifying the representations and processes underlying a cognitive function provides a foundation for interpreting deficits affecting that function. In particular, deficits are interpreted as resulting from dysfunction of one or more components of the normal cognitive system. Ideally, the interpretation specifies which component(s) of the normal system are malfunctioning, how and to what extent they are malfunctioning, and how the malfunction(s) give rise to the specific pattern of impaired performance observed in an individual with a deficit. We first illustrate this point through an example from the literature on acquired dysgraphia in adults, and then consider the role of the normal adult theory in the study of developmental dysgraphia.

Theory-Based Interpretation of Deficits

Goodman and Caramazza (1986a, 1986b) reported the case of JG, a young woman with a spelling deficit resulting from a head injury. JG's comprehension of dictated stimuli was intact, and she showed normal performance in spelling pseudowords (e.g., FEEN).[4] However, she was impaired in spelling words (e.g., CURTAIN), with errors taking the form of phonologically plausible misspellings (e.g., KERTIN). Her spelling performance also showed a regularity effect—better performance for words with spellings that are highly predictable from their sounds (e.g., CRIME) than for words with less predictable spellings (e.g., KNOCK). Finally, JG's performance pattern was virtually identical in written and oral spelling tasks.

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[3]Note that the terms *allograph* and *allographic* are used somewhat inconsistently in the literature. Whereas some authors use these terms to refer to letter shape representations with no motoric content, others use the terms in referring to what we have called graphic motor plans.

[4]A pseudoword spelling is scored correct if the spelling is plausible given the sound. Hence, for the dictated pseudoword /fi:n/, the spellings FEEN, FENE, and FEAN would all be counted as correct.

Goodman and Caramazza argued that JG suffered from a selective deficit affecting orthographic long-term memory, such that she was frequently unable to activate a learned spelling representation when attempting to spell a word. When retrieval of the orthographic representation failed, they argued, JG relied upon her intact sound-to-spelling conversion process to generate a spelling. These assumptions permit a clear and explicit interpretation for the various features of JG's spelling performance. Her spelling is impaired for words but not for pseudowords because orthographic long-term memory is required for accurate spelling of words but not pseudowords (which are spelled sublexically). Her errors for words take the form of phonologically-plausible misspellings because she often uses the sublexical sound-spelling conversion process to spell words, and this process generates spellings that, while plausible (e.g., KERTIN), are not always correct. The role of the sublexical route in JG's spelling of words also explains the regularity effect: When she is forced to rely on sublexical spelling processes, she is more likely to produce the correct spelling for highly regular words than for less regular words, precisely because the more regular words have spellings that are more likely to be generated by application of sound-spelling correspondence rules. Finally, JG's extremely similar performance in written and oral spelling tasks follows from basic assumptions about the functional architecture of the cognitive spelling mechanisms: written and oral spelling recruit the same lexical and sublexical spelling processes.

In addition to illustrating that a theory of normal cognitive representations and processes provides a basis for interpreting deficits, this example makes another, closely related, point: A theory of normal mechanisms is crucial for developing systematic diagnostic methods. In choosing which tasks to present (e.g., word and pseudoword spelling, written and oral spelling), which variables to manipulate (e.g., regularity), and which analyses to carry out (e.g., analyses of error types) Goodman and Caramazza (1986a, 1986b) were guided by the theory of normal cognitive spelling mechanisms. Taken together, the tasks, manipulations, and analyses they chose in studying JG systematically assessed each of the processing components specified in the theory. For example, the functioning of JG's sublexical sound-to-spelling process was assessed by examining her pseudoword spelling accuracy and her error types in spelling words. In the absence of a theory specifying the normal cognitive spelling mechanisms, Goodman and Caramazza would have had no solid basis for choosing diagnostic methods, or for interpreting results obtained with these methods.

Deficits as Evidence about Normal Mechanisms

Thus far, we have emphasized that a theory of normal cognitive mechanisms plays an essential role in efforts to understand cognitive deficits. At the same time, however, deficits provide evidence bearing on the theory of normal cognitive mechanisms, supporting, disconfirming, or prompting further elaboration of assumptions about normal cognitive representations and processes. For instance, the results from JG supported fundamental assumptions about the cognitive architecture of the normal spelling system, such as the assumption of separate lexical and sublexical spelling routes (supported by the findings pointing to selective impairment of the former while the latter remained intact). In addition systematic analyses of JG's phonologically plausible misspellings led Goodman and Caramazza to formulate claims about the functioning of the sublexical spelling process. For example, Goodman and Caramazza presented evidence that in selecting letters to represent sounds the sublexical process is context-sensitive, taking into account both syllable position (e.g., mapping /k/ to CK in syllable-final but not syllable-initial position) and the sound-letter mapping options chosen for adjacent positions in the word (e.g., mapping /s/ to C only when the letter selected for the immediately-following position was E, I, or Y, as in CENTER or JG's misspelling of SENATE as CENIT).

Developmental Dysgraphia and the Theory of Normal Adult Writing Mechanisms

The preceding discussion of cognitive theory and research on acquired dysgraphia has implications for the study of developmental dysgraphia. We assume that like acquired dysgraphias, developmental writing deficits can be interpreted by specifying which component(s) of the normal adult writing system (e.g., orthographic long-term memory, graphic motor plans) are deficient (which, in the case of developmental deficits, means that a component is less fully developed than expected).[5] Further, we assume that the study of developmental dysgraphia can shed light on normal cognitive writing mechanisms and their development. These assumptions may be incorrect, and indeed have been questioned in the context of other developmental deficits (e.g., Bishop, 1997; Karmiloff-Smith, 1997; but see Castles et al., 2014, for counterarguments). Conceivably, atypical development could give rise to cognitive mechanisms that are both non-optimal and radically different in structure and functioning from the mechanisms acquired by typically-developing children. If this were the case, we could not interpret deficits in terms of disruption to normal writing mechanisms, and we could not readily make inferences about the normal mechanisms from developmental writing deficits.

This possibility that individuals with developmental dysgraphia have grossly atypical cognitive writing mechanisms cannot be ruled out *a priori*. However, we suggest that neither should this possibility be assumed *a priori*. In our view it is more likely that in developmental dysgraphia some aspect(s) of an otherwise-typical system fail to develop fully, than that a completely different system is acquired. Regardless of relative likelihoods, however, we suggest that the appropriate research strategy is to adopt as a working hypothesis the normal-system-with-some-deficiency assumption, and ask whether the evidence comports with the assumption.[6] If the assumption is incorrect—that is, if individuals with developmental dysgraphia develop writing systems qualitatively different from those of typically-developing writers—we should soon discover the error. Efforts to interpret developmental writing deficits by specifying disruption to the normal cognitive writing system should prove unsuccessful; and conclusions we draw about normal writing mechanisms through studies of developmental dysgraphia should fail to converge with conclusions from studies of normal writing and studies of acquired dysgraphia. On the other

[5]The normal system that provides a basis for characterizing deficits in developmental dysgraphia is not the fully-developed adult system, but rather the partially-developed form of that system we would expect to find in a typically-developing child (e.g., the writing system of a typically-developing 8-year-old if we are considering a developmentally dysgraphic 8-year-old). Consequently, interpretation of developmental dysgraphias requires not only a theory of the adult system, but also assumptions about how this system typically develops over time. Although some researchers (e.g., Bishop, 1997) have argued that developing cognitive systems may be so different from adult systems that theories of adult systems are not useful in interpreting developmental disorders, Castles et al. (2014) make a strong case for the value of adult-system theories in the study of developmental deficits.

[6]This assumption is analogous to the assumption in adult cognitive neuropsychology that brain damage does not lead to creation of a cognitive system qualitatively different from the normal system (the "transparency" assumption; see Caramazza, 1986).

hand, if research founded on the normal-system-with-some-deficiency assumption proves fruitful in explaining deficits and advancing our understanding of normal writing processes, then we can have more confidence in the assumption. As we discuss in a later section the available research on developmental dysgraphia, although still somewhat limited, provides grounds for optimism that developmental writing deficits will prove to be interpretable by reference to the normal adult system.

The Developmental Dimension

The developmental aspect of developmental dysgraphia raises another set of issues we have not yet considered. In acquired deficits (at least those with onset in adulthood) a cognitive system has developed normally, and then suffers disruption as a consequence of brain damage. In developmental deficits, however, the deficiency within the cognitive system occurs due to some malfunction in processes that support acquisition of the system. In the case of writing ability, the relevant knowledge and cognitive processes must be learned, and impairment affecting the ability to learn the knowledge and processes leads to deficiencies in the writing system.

Consider, for example, a deficit affecting orthographic long-term memory, in which an individual often cannot access representations of whole-word spellings. If this were an acquired deficit, we would assume that brain damage disrupted previously-learned spelling representations, and/or the ability to retrieve these representations from orthographic long-term memory. However, if the deficit were developmental, we would likely assume that the individual was impaired in learning the spelling representations (or perhaps the procedures for retrieving the representations from memory). In this case—and indeed for any developmental deficit—interpreting the deficit involves not only specifying what component(s) of the writing system is/are deficient, but also characterizing the deficit/s that led to impaired acquisition of the representations or processes making up the component.

This point brings up an important distinction, articulated by Coltheart (2015), between proximal and distal causes (see also Castles et al., 2014). Proximal causes are the deficiencies within a cognitive system that directly result in impaired performance, whereas distal causes are the causal factors that produced the deficiencies. In a case of developmental dysgraphia the proximal cause is the deficiency within the cognitive writing system that produces impaired writing performance (e.g., underdeveloped orthographic long-term memory, deficient knowledge of sound-spelling correspondence rules). The distal cause, in contrast, is the deficit that caused the failure in acquisition of cognitive spelling or handwriting mechanisms. For example, a deficit in encoding or retaining information about ordering of elements (such as the letters in a word) could impair the learning of word spellings, resulting in deficient orthographic long-term memory representations. In this instance, the distal cause is the deficit in sequence representation, and the proximal cause is the deficient orthographic long-term memory system.

Claims about proximal and distal causes address different questions, and should be carefully distinguished in theorizing about developmental dysgraphia. Claims about proximal causes speak to the question, What aspect(s) of the cognitive writing system are deficient?, whereas for distal causes the question is, What caused the failure of development for the deficient writing-system components? Hence, proximal-cause interpretations (e.g., orthographic long-term memory deficit) are not alternatives to distal-cause accounts (e.g., impaired visual attention span). Rather, proximal- and distal-cause claims together provide a fuller interpretation for an impairment than either alone.

Of course, an adequate distal-plus-proximal-cause account should make clear how the proposed distal cause led to the posited proximal deficit. For example, if the proximal cause is claimed to be a deficient orthographic long-term memory, the distal cause should plausibly lead specifically to difficulty in learning word spellings.

Two points about distal causes merit brief discussion. First, although distal causes are typically assumed to involve rather general cognitive processes (e.g., learning, visual attention, or other processes implicated in a broad range of cognitive functions), distal causes could conceivably also include highly specific processes. For example, in an individual with a deficient orthographic long-term memory, the distal cause could conceivably be a highly selective deficit in learning word spellings, occurring in the presence of otherwise normal learning abilities; or the individual might have a learning deficit that, while not entirely specific to spelling, nevertheless affects learning only in a limited range of circumstances (e.g., a deficit in learning information in which the ordering of elements is critical).

Second, the distal cause for a deficit is probably best thought of not as a single causal state or event, but rather as a complex causal nexus that may include causes at several levels of explanation (e.g., cognitive, neural, genetic). For example, a genetic defect might (via several intervening causes) lead to an impairment in sequence encoding, which in turn causes a proximal deficit in orthographic long-term memory (see Coltheart, 2015, for further discussion). However, we limit our discussion of distal causes to the cognitive factors that most directly give rise to the proximal writing-system deficit.

Acquisition of Writing Ability

Our ability to understand the proximal and distal causes of developmental dysgraphias will depend importantly on our understanding of the processes involved in the normal acquisition of writing skills. Although some research has examined acquisition of spelling and handwriting (e.g., Apel, 2009; Berninger et al., 2006; Kersey & James, 2013; Kandel & Perret, 2015; Kandel & Valdois, 2006; Masterson & Crede, 1999; Treiman, 1993; Treiman & Kessler, 2014), we do not yet have a comprehensive theory of the processes implicated in development of writing skill, or the cognitive capacities required by these processes. Here we provide a very brief overview of this complex topic.

The end state of learning to write is the adult writing system schematized in Figures 1 and 2. How, though, is this system acquired? The acquisition process draws upon a broad range of abilities that are available to children when they begin learning to write, including spoken language, vision, attention, memory, and motor skills. More specific cognitive capacities that may be important for acquisition of writing include, but are not limited to, phonological awareness and phonological memory (Campbell & Butterworth, 1985; Snowling, Stackhouse & Rack, 1986), visual attention span (Valdois et al., 2003), visual memory (Goulandris & Snowling, 1991), and processes for representing the order of elements in a sequence (e.g., Romani, Ward, and Olson, 1999).

With regard to the trajectory of writing acquisition, the process of learning to spell has most often been described in terms of stage theories (e.g., Gentry, 1982; Ehri, 1986; Frith, 1980). The various proposals differ in their specific assumptions, but most posit some type of preliterate stage in which children realize that written marks (other than drawings) can be used to represent meanings, followed by a phonological stage during which letters are used to represent sounds, and then one or more orthographic stages in which letters, letter groups, orthographic regularities and eventually morphological information are incorporated into the spelling process. Importantly, however, Treiman and colleagues have shown that children begin to use various types of knowledge earlier than stage theories would predict. For example, children who would be classified as phonetic spellers nevertheless show evidence of familiarity with orthographic conventions concerning such matters as letter doubling (Treiman, 2003) and morphological boundaries (for more detailed discussion see Treiman & Bourassa, 2000; Pollo, Kessler & Treiman, 2009; Treiman, 1993; Treiman & Kessler, 2014). Treiman and colleagues conclude that spelling development is not characterized by strict stages in which children draw solely upon only a particular type of knowledge (e.g., phonological as opposed to orthographic). Rather, they argue, multiple knowledge types are brought into play throughout the acquisition process, and stages can be more appropriately thought of as developmental time-periods marked by the predominant (but not exclusive) use of certain knowledge types (see also Temple, 1990; Varnhagen, McCallum, & Burstow, 1997).

Turning now to development of handwriting, the required motor control is quite demanding, and children's writing of letters is initially slow and variable. Only with extensive practice, around age 10–11, does letter production become automatized, fast, and less variable (e.g., Halsband & Lange, 2006; van Galen, Portier, Smits-Engelsman, & Schomaker, 1993; see also Palmis, Dann, Velay, & Longcamp, 2017, in this special issue). Once handwriting is automatized, children can devote resources to other aspects of writing, such as sentence construction and text elaboration (Maggio et al., 2011; Pontart et al., 2013). Kandel and Perret (2015) argue that other consequences of growing automaticity include increasing interaction between central orthographic processing levels and more peripheral motor processes.

These proposals regarding normal spelling and handwriting acquisition represent valuable contributions to our understanding of writing development and developmental dysgraphia. Even taken together, however, they do not constitute a systematic theory of the knowledge and processes underlying the development of writing ability, and do not provide a firm foundation for systematically enumerating the possible distal causes for a developmental writing deficit. Therefore, a critical goal for research on developmental dysgraphia is the articulation of a more complete theory of writing acquisition.

Developmental Dysgraphia: Current State of Knowledge

The preceding discussion of normal adult writing mechanisms and their development provides a basis for considering the current state of knowledge regarding developmental dysgraphia. Here we provide a brief review of research regarding the proximal and distal causes.

Proximal Causes

A growing literature describes individuals with developmental spelling deficits that closely resemble acquired forms of dysgraphia, and can be understood as failures in developing particular components of the normal adult spelling system: orthographic long-term memory, the sublexical sound-to-spelling conversion process, or orthographic working memory (see Castles & Coltheart, 1993, for similar claims regarding developmental dyslexia).

Multiple reports have described individuals with developmental writing deficits attributable to a deficient orthographic long-term memory (as in the acquired case of JG studied by Goodman & Caramazza, 1986a, 1986b). Briefly, these individuals are impaired in spelling words (especially irregular words), and produce phonologically plausible errors, but have little or no difficulty spelling pseudowords. This pattern, sometimes referred to as developmental surface dysgraphia, has been reported in several languages (English: Brunsdon, Coltheart & Nickels, 2005; Coltheart et al., 1983; Goulandris & Snowling, 1991; Hanley & Gard, 1995; Hanley & Kay, 1992; Romani, Ward & Olson, 1999; Seymour & Evans, 1993; Seymour, 1986; Temple, 1985, 1986; Italian: Angelelli et al., 2004; Angelelli et al., 2010; Spanish: Afonso, Suarez-Coalla & Cuetos, 2015; German: Stadie & van de Vijver, 2003; Cholewa, Mantey, Heber & Hollweg, 2010; see also, in this special issue, Angelelli, Marinelli, Cellini, & Zoccolotti, 2017; Hanley & Sotiropolous, 2017; and Hepner, McCloskey & Rapp, 2017).

The complementary pattern—better spelling performance for words than pseudowords—has also been reported (Campbell & Butterworth, 1985; Cholewa et al., 2010; Funnell & Davison, 1989; Snowling, Stackhouse and Rack, 1986; Temple, 1986; Temple & Marshall, 1983). This pattern, often labelled developmental phonological dysgraphia, can be understood as a selective deficit affecting the sound-to-spelling conversion process. In addition a few cases of developmental impairment in orthographic working memory have been reported (Roncoli & Masterson, 2016; Yachini & Friedmann, 2010). For example, Roncoli and Masterson (2016) described a ten-year old boy who showed a pattern of spelling performance resembling that observed in acquired cases of orthographic working memory impairment: poor spelling of both regular and irregular words; errors in the form of letter omissions, insertions, substitutions, and transpositions; and effects of word length but not word frequency on spelling accuracy (see also Barisic, Kohnen, & Nickels, 2017, in this special issue).

Distal Causes

Notwithstanding the limitations in our current knowledge concerning acquisition of writing ability, some progress has been made in exploring distal causes of developmental dysgraphia. The most commonly proposed distal cause is a deficit in phonological processing and/or phonological awareness, suggested by reports of phonological deficits in some individuals with developmental dysgraphia (e.g., Campbell & Butterworth, 1985; Snowling et al., 1986; but see Castles & Coltheart, 2004). According to this proposal, learning to spell (like learning to read) requires an explicit understanding that spoken words are composed from smaller phonological units (i.e., phonemes), as well as an ability to parse words into their constituent phonemes at a level of processing accessible to awareness. Individuals with deficiencies in these phonological skills might therefore have difficulty appreciating the relationships between the sounds and spellings of words, leading to difficulty in learning sound-spelling correspondences, and in memorizing whole-word spellings. Despite the apparent plausibility of this argument, we are not aware of any clear evidence for a causal link between phonological deficits and developmental dysgraphia (see, e.g., Castles & Coltheart, 2004). Also, numerous cases of developmental dysgraphia have been reported in which phonological processing skills were intact (Angelelli, et al., 2004; Masterson, Laxon, Lovejoy & Morris, 2007; Holmes & Quinn, 2009; Frith, 1978, 1980; Hanley, Hastie & Kay, 1992; Hepner et al., 2017; Roncoli & Masterson, 2016; Romani et al., 1999). These cases demonstrate at the least that phonological impairment is not the sole distal cause of developmental dysgraphia.

Goulandris and Snowling (1991) suggested that deficits in the visual domain could lead to developmental dysgraphia. These researchers presented evidence of a visual memory impairment in an individual with developmental dysgraphia, and reasoned that the visual deficit would make it difficult to retain the information needed for building orthographic long-term memory representations. Also, Romani et al. (1999) described an individual with a deficit in encoding and learning the ordering of elements in a sequence of symbols (e.g., the ordering of letters in a written word), and argued that this sequence encoding deficit was the distal cause for the individual's developmental dysgraphia. (Romani et al. also presented evidence that the individual was intact in phonological processing and visual memory.)

With respect to developmental handwriting deficits, some form of motor-control deficit has most commonly been proposed as the distal cause (e.g., Smits-Engelsman & van Galen, 1997; Smits-Engelsman, Niemeijer, & van Galen, 2001; van Galen et al., 1993). For example, van Galen et al. (1993) argued that poor writers are deficient at inhibiting noise in their neuromotor systems. Developmental handwriting deficits could also conceivably result from distal deficits that impair the learning of effector-independent or effector-specific motor programs for characters.

These various results suggest that multiple forms of underlying impairment may lead to developmental dysgraphia. As our understanding of normal writing acquisition advances, we will have a stronger foundation for systematically exploring possible distal causes, and relating these to particular types of proximal impairment within the writing system.

An Agenda for Research on Developmental Dysgraphia

The preceding discussion and overview of the literature provides a basis for defining an agenda for the study of developmental dysgraphia. The agenda has two closely-interrelated goals: 1) advancing our understanding of the proximal and distal deficits underlying developmental writing impairments; and 2) advancing the development of theories concerning normal cognitive writing mechanisms and the development of these mechanisms. Many aspects of the agenda are already being pursued, and we hope that this special issue will contribute to moving the agenda forward.

With respect to characterizing the underlying deficits in developmental dysgraphia, we suggest that a fruitful research agenda can be defined by the following fundamental questions:

- What aspects of the cognitive writing system show impairment in cases of developmental dysgraphia (proximal causes)?
- What distal causes are implicated in the genesis of these deficits?
- How are distal and proximal causes linked? That is, how does each proximal deficit in cognitive writing mechanisms arise from the associated distal cause(s)?

These questions cannot, however, be addressed in isolation. As we have emphasized, answers must be built on a solid foundation of theory concerning normal cognitive writing mechanisms, and the development of these mechanisms. Hence, the second part of our proposed agenda concerns advancement of theory in these areas. The basic questions are as follows:

- What cognitive representations and processes underlie normal spelling and writing?
- How do these cognitive mechanisms develop as a child learns to write?

As we have discussed, considerable progress has been made regarding the first question: We have a reasonably well-specified theory of normal adult writing mechanisms. As with any cognitive theory, many aspects of the writing theory are in need of further development (and even the most basic assumptions of the theory could ultimately turn out to be wrong).[7] Nevertheless, the theory is sufficiently well-developed and well-supported that we can (at least to a first approximation) enumerate the possible proximal causes of developmental writing deficits, and investigate these systematically.

In contrast, our knowledge concerning the acquisition of writing is not as far advanced, and consequently our foundation for elucidating distal causes of developmental dysgraphia is less complete. We hope that research on developmental dysgraphia will both contribute to, and benefit from, progress in our understanding of the normal development of writing ability.

[7]One important set of unresolved questions concerns relationships between writing and reading mechanisms (e.g., Coltheart & Funnell, 1987; Jones & Rawson, 2016; Tainturier & Rapp, 2001). For example, does a single orthographic long-term memory underlie both reading and spelling, or are there instead separate input (reading) and output (spelling) orthographic long-term memory systems, each specialized to perform different computations (mapping letter to word representations in reading, and word to letter representations in writing)? Research on developmental dysgraphia research may shed light on these issues (see, e.g., Hepner et al., 2017, and Hanley & Sotiropoulos, 2017, in this special issue).

Throughout this article we have focused on cognitive as opposed to neural representations and processes, because at present we have only limited knowledge about neural mechanisms in spelling and handwriting, and especially about neural dysfunctions in developmental dysgraphia. Accordingly, yet another important goal for future research is to advance our understanding of neural mechanisms and dysfunctions in writing and dysgraphia. (For discussions of neural substrates of writing see, e.g., Beeson et al., 2003; Palmis et al., 2017; Planton, Jucla, Roux, & Démonet, 2013; Purcell, Turkeltaub, Eden, & Rapp, 2011; Rapp & Dufor, 2011.)

In pursuing the research agenda we have sketched, it is important to recognize that developmental dysgraphias are heterogeneous, with respect to both proximal and distal causes. The writing system is complex, encompassing a broad range of cognitive and neural representations and processes. Disruption to any of these could potentially result in a writing deficit, with the nature of the deficit depending on the nature and extent of the disruption. Consequently, we should not expect disruption to the writing system (the proximal cause) to be the same in everyone suffering from developmental dysgraphia. To the contrary, we should recognize that deficits grouped under the heading developmental dysgraphia are diverse. Research on acquired dysgraphia in adults makes clear that there are multiple distinct forms of writing-system impairment, including but not limited to selective deficits affecting orthographic long-term memory (e.g., Beauvois & Dérouesné, 1981; Goodman & Caramazza, 1986a, 1986b), sublexical sound-to-spelling conversion (e.g., Shallice, 1981), orthographic working memory (e.g., Caramazza & Miceli, 1990; Caramazza, Miceli, Villa, & Romani, 1987; McCloskey, Badecker, Goodman-Schulman, & Caramazza, 1994; Posteraro, Zinelli, & Mazzucchi, 1988), and graphic motor plans (e.g., Baxter & Warrington, 1986; Miozzo & De Bastiani, 2002). Furthermore, these diverse cognitive dysfunctions are associated with diverse loci of neural dysfunction (e.g., Rapp et al., 2015). The evidence we have surveyed on developmental dysgraphia indicates that this category is comparably heterogeneous.

Similarly, with respect to distal causes, diverse proximal deficits are likely to stem from diverse distal impairments (e.g., impairments in phonological processing, visual memory, or sequence encoding). In addition, similar proximal deficits could potentially arise from quite different distal causes. For example, a deficient orthographic long-term memory could potentially result from several different distal causes, all of which cause difficulty in learning of word spellings.

This point has two crucial consequences. First, we should not take the goal of research to be that of determining *the* (proximal or distal) cause of, or *the* underlying (proximal or distal) deficit in, developmental dysgraphia. Almost certainly there are multiple proximal and distal causes that can lead to developmental writing deficits, and our goal should be to characterize the full constellation of these proximal and distal causes. The second consequence concerns research strategy: We cannot conduct research by selecting a group of developmental dysgraphics according to some diagnostic criteria, and then studying them as a group (e.g., averaging results across participants, looking for significant group effects). This research method assumes the group to be homogeneous in relevant respects, and in particular assumes that all have the same form of impairment. Rather, we must study participants individually, allowing commonalities and differences across individuals to emerge from the conclusions of detailed single-case investigations, rather than being assumed *a priori*.[8]

Overview of the Special Issue

The articles in this special issue explore many of the research topics we have discussed, and contribute to advancing the agenda we have outlined. The first five articles focus primarily on spelling, whereas the final three address issues concerning handwriting.

Treiman (2017) reviews typical spelling development, with particular emphasis on sublexical spelling processes. Treiman argues that spelling patterns (regularities in sound-spelling mappings) are complex and multi-faceted, and hence that acquisition of sublexical knowledge is not a simple matter of learning context-free phoneme-grapheme mappings. She describes an Integration of Multiple Patterns (IMP) framework, according to which children learn not only whole-word spellings, but also context-sensitive phonological, graphotactic, and morphological patterns that apply (although not without exceptions) to many words. For example, Treiman notes that /ɛ/ is typically (though not always) spelled EA when followed by D (e.g., HEAD), but as E when followed by other consonants (e.g., GET). She proposes that statistical learning processes play an important role in learning of spelling patterns, and also suggests that learning a whole-word spelling is easier when multiple patterns converge on the correct spelling, than when patterns conflict. Treiman's arguments and proposals have important implications for theory and research concerning normal spelling processes, the acquisition of spelling, and the nature of the deficiencies in developmental spelling deficits.

Barisic, Kohnen, & Nickels (2017) report a single-case study of a 10-year-old boy, LS. Examining LS's performance across a variety of tasks chosen to probe the various components of the normal adult spelling system, Barisic and colleagues conclude that he suffers from a developmental deficiency at the level of the graphemic buffer (orthographic working memory). For example, like reported acquired cases of graphemic buffer impairment, LS predominantly makes letter errors in spelling (i.e., letter substitutions, transpositions, additions, and omissions). The Barisic et al. study adds to our understanding of the forms of developmental spelling impairment, as well as supporting the view that cognitive neuropsychological methods can fruitfully be applied to developmental deficits. In particular, the study highlights the value of theory-based assessment and interpretation of developmental dysgraphias.

Hepner, McCloskey, & Rapp (2017) also apply theoretically-grounded cognitive neuropsychological methods in their study of two children, PJT and AKR, who present with poor spelling in the context of otherwise strong cognitive abilities. Hepner et al. argue that both children are impaired in learning lexical orthographic representations for use in spelling (with PJT also showing deficiency in sublexical spelling processes), and examine potential distal causes for the spelling deficits. They also report a striking dissociation for PJT

[8]This same point has been discussed extensively in the context of acquired deficits (see Caramazza & McCloskey, 1988; McCloskey & Caramazza, 1988).

between reading and spelling. Whereas PJT's spelling is severely deficient, a thorough assessment of his reading revealed normal (and in fact exceptionally strong) performance, with no evidence of weakness in either lexical or sublexical reading processes. This result has implications for issues concerning normal reading and spelling processes (e.g., shared vs. separate orthographic lexicons for reading and spelling), and suggests that at least some aspects of lexical orthographic representation and processing develop with considerable independence in reading and spelling.

Sotiropolous and Hanley (2017) also address issues concerning shared vs. separate cognitive mechanisms for reading and spelling. These authors report intriguing results from six university students with developmental spelling and reading deficits. All six participants showed the same basic pattern of performance on reading and spelling assessment tasks (e.g., impaired reading and spelling of irregular words, but intact reading and spelling of pseudowords). This pattern is typically labeled surface dyslexia and dysgraphia, and is usually interpreted to reflect impaired lexical and intact sublexical reading and spelling processes. However, despite the similarity across participants in basic reading and spelling performance, testing with additional tasks (e.g., lexical decision, semantic decision, written picture naming) revealed clear differences among participants, indicating differences in the underlying impairments. In interpreting the observed performance patterns, Hanley and Sotiropolous argue that a single orthographic system mediates both reading and spelling. In addition to the specific empirical and theoretical contributions of the study, the Hanley and Sotiropolous findings highlight two points we have emphasized in the present article: First, developmental dysgraphias (and dyslexias) are diverse, with multiple causes and manifestations; and second, detailed, theory-guided testing of individuals is necessary to identify the nature of the impairments.

Marinelli, Cellini, Zoccolotti, and Angelelli (2017) examine lexical and sub-lexical reading and spelling processes in Italian, a language with a largely transparent orthography. Angelelli and colleagues tested typically developing and dyslexic third- and fifth-grade children on spelling to dictation and orthographic judgment (i.e., lexical decision) tasks. Stimuli included not only words with regular spellings (which make up most of the Italian lexicon) but also words for which the spelling is not entirely predictable from the phonology (e.g., CUOCO, which is not fully predictable because /kw/ may be realized in Italian as either CU or, less commonly, as QU). In both spelling and orthographic judgment tasks, and for both typically-developing and dyslexic children, results indicated that children were relying in part on lexical orthographic knowledge in performing the tasks (e.g., frequency and regularity effects were observed). However, the lexical knowledge was weaker in the dyslexic children (as evidenced, for example, by larger regularity effects for dyslexic than typically developing children). Also, both dyslexic and typically-developing children were sensitive to the frequencies of grapheme-phoneme mappings in Italian. For example, in spelling low-frequency words children were more accurate for those with high-frequency mappings (e.g., /kw/ → CU) than for those with low-frequency mappings (e.g., /kw/ → QU). Angelelli et al. suggest that sublexical knowledge, including knowledge about frequencies of sound-spelling mappings, contributes to lexical learning and, in dyslexic children, can compensate in part for deficient lexical-orthographic knowledge.

The final three articles in the special issue concern handwriting development and developmental handwriting deficits. **Palmis, Danna, Velay, and Longcamp** (2017) provide an overview of the cognitive and neural mechanisms in adult handwriting and typical handwriting development. Emphasizing the complex motor control processes required for handwriting, these authors characterize skilled handwriting in adults, and then describe how writing is acquired over a number of years in childhood. According to Palmis and colleagues, acquisition of handwriting involves a variety of developmental changes, including a transition from production of characters as a series of discrete strokes (often separated by pauses or pen lifts) to a smoother, less variable, and more automatic production under the control of learned whole-character motor representations. Palmis et al. also offer insights into the brain networks that contribute to handwriting performance, and the neural changes that occur in the course of handwriting development. This article provides a foundation for considering the nature of the proximal and distal deficits in children with developmental handwriting deficits.

Prunty and Barnett (2017) contrast children who have handwriting difficulties as a consequence of a general motor coordination deficit (developmental coordination deficit, or DCD) with children who struggle with handwriting in the absence of general motor impairment (referred to as dysgraphic children). DCD and dysgraphic groups were compared with typically developing control children on a variety of handwriting measures, including writing speed, pauses during writing, and quality of letter formation. Although the DCD and dysgraphic children performed more poorly than the typically developing children on most measures, few differences were found between the DCD and dysgraphic groups. However, considerable variation was observed within groups. These results highlight the importance—for diagnosis, remediation, and research—of considering children as individuals, and not just as members of a category such as DCD.

Finally, in a fitting conclusion to the special issue **Kandel, Lassus-Sangosse, Grosjacques, and Perret** (2017) bring together the study of spelling and the study of handwriting. Although spelling and handwriting are usually treated separately in theory and research, Kandel and colleagues have argued previously that cognitive spelling processes (e.g., retrieval of lexical orthographic representations) are not completed prior to initiation of writing (e.g., Roux, McKeeff, Grosjacques, & Kandel, 2013). Rather, the spelling processes are ongoing during the production of written output, and may affect the motor processes in handwriting. Applying this perspective to the study of children diagnosed with developmental dysgraphia, Kandel and colleagues argue that in children who have difficulty spelling, the greater-than-normal cognitive load imposed by spelling processes may lead to handwriting deficiencies, including slow and dysfluent writing. In fact these authors suggest that the frequently-observed poor handwriting in children with spelling deficits may often stem from the effects of spelling processes on handwriting, and not from deficiencies in handwriting perse.

We hope that this special issue will prove useful to researchers, educators, and clinicians interested in normal or impaired reading or writing. We especially hope that the special issue will stimulate further discussion and research on the important but understudied topic of developmental dysgraphia.

Acknowledgments

Preparation of this article was supported by a Johns Hopkins Science of Learning Institute grant to Michael McCloskey and by National Institutes of Health Grant DC006740 to Brenda Rapp, and by a generous gift from a donor to the Johns Hopkins University.

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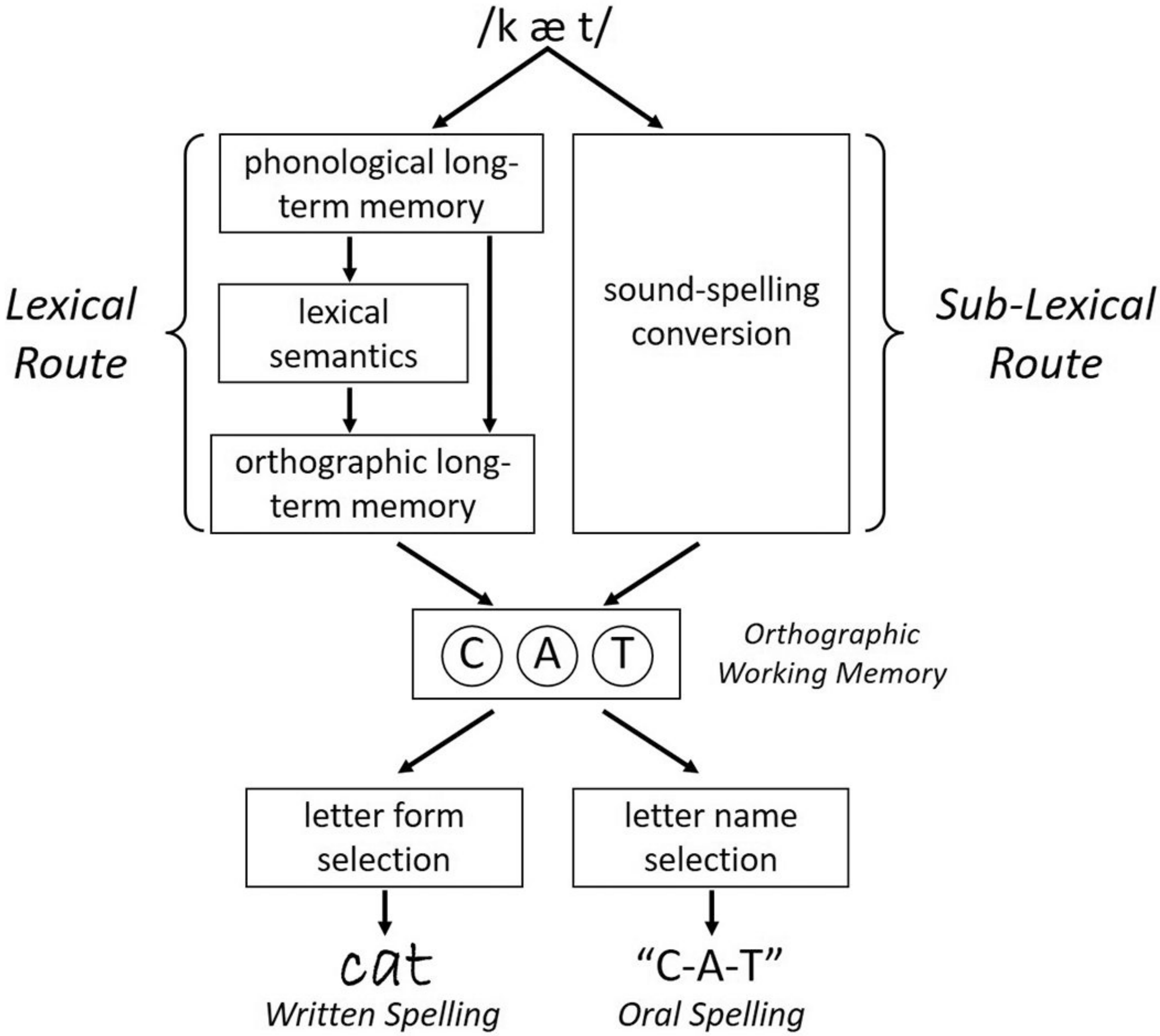

Figure 1.
Schematic depiction of the cognitive mechanisms making up the normal adult writing system.

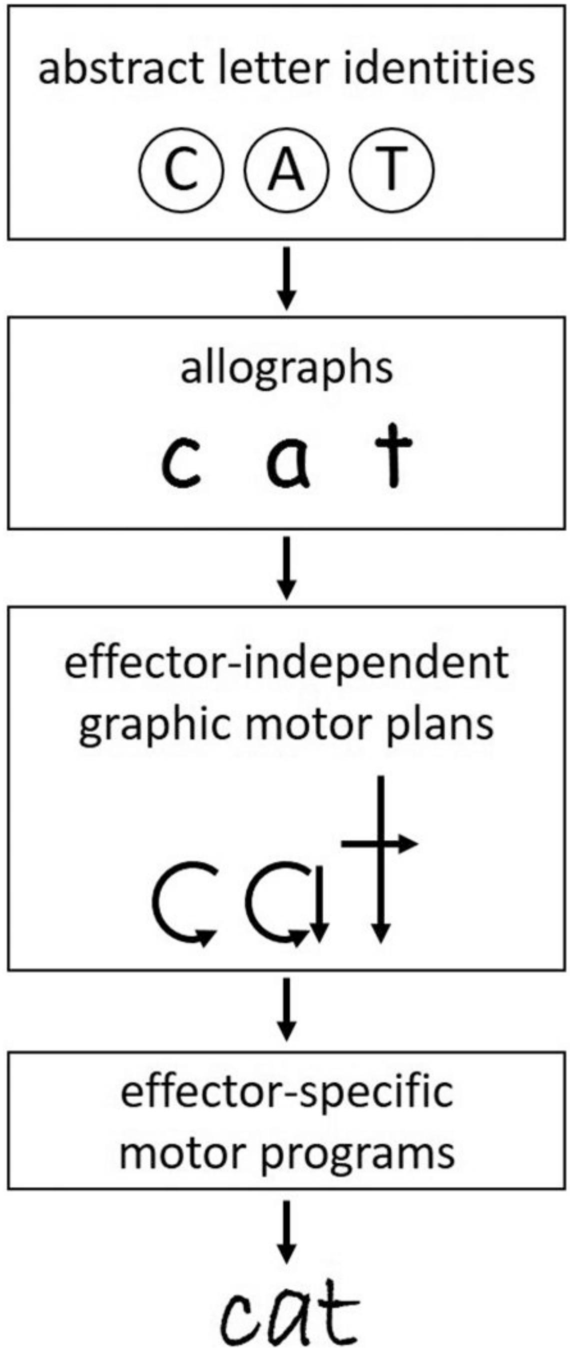

Figure 2.
Schematic depiction of the cognitive handwriting mechanisms, which map abstract letter identities onto motor programs for production of written responses.