Types of developmental dyslexia

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To the best of our knowledge, the first person to suggest that there are different types of developmental dyslexia was the educational psychologist Helmer Myklebust. In Myklebust (1965), he suggested that some dyslexic children have difficulty in learning to read because they "could not acquire the auditory equivalents of the appearances of the letters" (p. 30: Myklebust referred to this condition as "auditory dyslexia"), whilst for other dyslexic children the problem is "the inability to mentally visualize letters and sounds" (p. 23: Johnson and Myklebust, 1967, referred to this condition as "visual dyslexia"). These ideas were taken up by the pediatric neurologist Elena Boder (see for example Boder, 1968, 1969, 1970, 1971, 1973). She developed a diagnostic screening test based on the distinction between auditory and visual dyslexia and this allowed her to characterize these two subtypes in a little more detail.

She proposed (see e.g. Boder, 1973) that some dyslexic children, when attempting to read aloud words that are not in their sight vocabularies, are typically unable to do so because they are "unable to sound out and blend the component letters and syllables of a word" (p. 688). This is Myklebust's auditory dyslexia. Boder referred to it as "dysphonetic dyslexia". These days the form of developmental dyslexia in which there is a specific difficulty in reading aloud unfamiliar letter strings is called "developmental phonological dyslexia".

A second group identified by Boder (1973) were those dyslexic children who are "analytic readers" and read "by ear", "through a process of phonetic analysis and synthesis, sounding out familiar as well as unfamiliar combinations of letters, rather than by whole-word gestalts. . . [they] can often read the word list by phonetic analysis up to or near [their] grade level, missing out only words that cannot be decoded phonetically" (that is, irregular words). This is Myklebust's visual dyslexia. Boder referred to it as "dyseidetic dyslexia". These days the form of developmental dyslexia in which there is a specific difficulty in reading irregular words aloud is called "developmental surface dyslexia".

At the same time as these early ventures into the subtyping of developmental dyslexia were proceeding, work on subtyping of acquired dyslexia, dyslexia following brain damage, was also beginning to develop. Marshall and Newcombe (1966) offered a detailed description of one such dyslexia type, acquired deep dyslexia, the identifying symptom of which was the frequent occurrence of semantic errors in reading aloud single words. This work was developed further by Marshall and Newcombe (1973), who described the characteristics of three types of acquired dyslexia: as well as deep dyslexia, there was visual dyslexia (which was not the same as the visual dyslexia described by Myklebust and Boder: see below for further discussion of visual dyslexia), and there was a form of acquired dyslexia in which the patient can no longer recognize many formerly familiar words and so can only read them aloud by sounding them out, a process which will fail for irregular words. This is Myklebust's "visual dyslexia" and Boder's "dyseidetic dyslexia", but Marshall and Newcombe (1973) introduced the term "surface dyslexia" for this condition, and that became the standard term. As for the acquired analogue of Myklebust's "auditory dyslexia" and Boder's "dysphonetic dyslexia" – a specific loss of the ability to read aloud unfamiliar letter strings such as nonwords – this was first described by Beauvois and Derouesne (1979; Derouesne & Beauvois, 1979) and referred to as "phonological alexia", a term that soon became "phonological dyslexia". The unification of these originally separate and parallel endeavours – the subtyping of developmental dyslexias and the subtyping of acquired dyslexia – was obviously desirable. Such unification was the aim of a NATO conference held at Maratea, Italy, in October 1982, and published as a book "Dyslexia: A global issue", edited by Malatesha and Whitaker (1984). The two critical papers here are by John Marshall: one was entitled "Towards a rational taxonomy of the developmental dyslexias" (Marshall, 1984a) and the other "Towards a rational taxonomy of the acquired dyslexias" (Marshall, 1984b).

The key point made in these two papers was that both developmental and acquired types of reading disorder need to be interpreted in relation to a model of intact adult skilled reading. Such a model defines the various components of the reading system that children must learn if they are to become skilled readers; and it defines the various components of the reading system any one of which can be individually impaired. Such

selective impairment can either be caused by a developmental disorder, or by brain damage, after the relevant component of the reading process has already been fully acquired. Both developmental and acquired disorders produce some particular patterns of preserved and impaired reading abilities – that is, some specific types of acquired dyslexia. So any such model can be used to interpret both developmental and acquired dyslexias; and in addition such models are invaluable for the development of rational assessment procedures and for the design of rational treatment regimes.

Furthermore, the identification and characterisation of various types of dyslexia, in turn, provide constraints for the cognitive model of reading and suggest modifications to it. One example of a fruitful interaction between the reading model and dyslexias can be seen in the case of the functions of the orthographic-visual analyser. In 1977, Shallice and Warrington described a patient who had migrations of letters between words when he was reading words that were presented one next to the other. This dyslexia was later termed (in Shallice and Warrington's 1980 chapter) "attentional dyslexia". One important characteristic of these migrations between words was that letters that migrated to the other word still kept their original position within the word (i.e., the final letter migrates to the final position in the other word, etc.). This finding not only sheds light on the characterisation of this dyslexia but also informs the cognitive theory of the first stage of word reading, because it implies that the function that encodes the position of letters within the word and the function that binds a letter to the word it appears in are separate. And this is indeed how the functions of the orthographic-visual analyser were portrayed since then. Ellis and Young (1988), for example, described the orthographic-visual analyser as involving, in addition to letter identification, two separate functions of position encoding: letter position within words and letter-to-word binding.

The next step of interaction between developmental dyslexia and the reading model came from the other direction, of the model informing dyslexia research. Friedmann and Gvion (2001, and Friedmann & Rahamim, 2007) reasoned that if a function of letter position encoding exists and is a separate function, a dyslexia should exist that results from a selective deficit to this function. Using words that would be sensitive for this kind of impairment, those in which letter position errors create

other existing words, they were able to identify this dyslexia, now called "letter position dyslexia", in both acquired and developmental cases. Without the insights from dyslexia, we would not know that the two functions are separate; without the model, this letter position dyslexia may not have been sought for and identified, and relevant treatment would not be developed.

Model of word reading

Thus, before we can describe the types of developmental dyslexia, each resulting from an impairment in a different component of the reading model, we start by describing the various components of the dual route model for single word reading, the model that is currently able to explain and predict most known types of dyslexia.
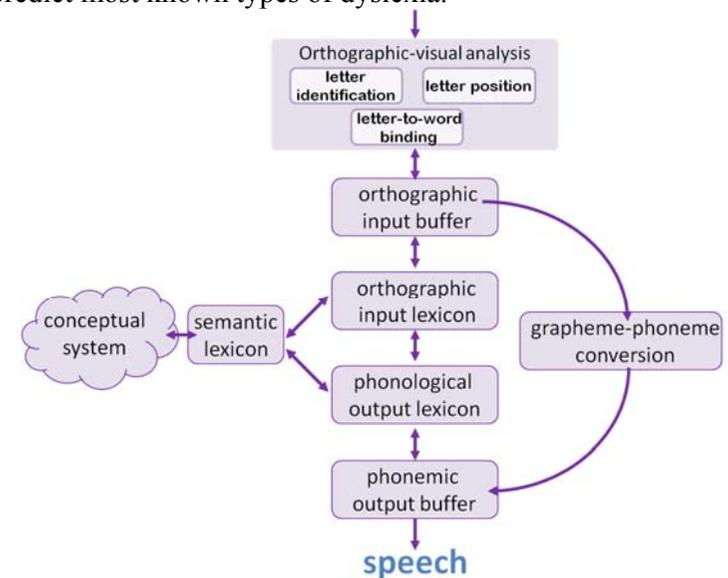

Figure 1. The dual route model for single word reading

Figure 1 depicts the dual route model. According to this model, the first stage that a written word undergoes is early analysis in the orthographic-visual analysis system. This early stage is responsible for the identification of the letters, the encoding of the position of each letter within the word, and binding of letters to words (Coltheart, 1981; Ellis,

1993; Ellis, Flude, & Young, 1987; Ellis & Young, 1988; Humphreys, Evett, & Quinlan, 1990; Peressotti & Grainger, 1995).

The abstract letter identification stage involves identifying the letter. In this stage, a ɑ *ə* ɑ A **A** *A* **A** will all be stripped of their font and size and be identified as the same abstract letter, still without its sound or name. Letter identity is not enough: to read a word like *clam*, for example, the abstract identities of the letters within it would not suffice, because this might lead to reading it as "calm". Therefore, another important function in the early analysis that needs to be performed before access to the lexicon is letter position encoding. This process encodes the positions of letters in the word, relative to the first and final letter positions.

Reading usually does not involve only a single word, but rather a word in the context of other words. Therefore, another function that is required for correct reading is attenuating the words around the target word, and binding letters with words, allowing for the identification of the letters as part of a specific word.

The output of the orthographic-visual analysis processes is then held in an orthographic short-term store, the orthographic input buffer, until this information can be fully processed by the following components. As a short term memory store, this buffer is sensitive to word length.

Another process that takes place in the pre-lexical stage of word reading, possibly in the orthographic input buffer, is morphological decomposition (Taft, in press): Words are stored in the orthographic input lexicon decomposed to their stems (for example, the lexicon includes an entry for *bird* and not for *birds*). Therefore, for the words to be identified in the lexicon, they have to be served to the lexicon in a way that it can find them – that is, in a decomposed way. Thus, prior to access to the orthographic input lexicon, morphologically complex words like "birds", "walked", or "ferries" are decomposed to their morphological constituents. The stems (*bird, walk, ferry*) then activate the relevant entries in the orthographic lexicon, whereas the morphological affixes activate their corresponding entry in a separate morphological output store (probably in the phonological output buffer, Dotan & Friedmann, 2015), and their relevant meaning, if they have a transparent meaning component (-*s* in *birds* has a transparent plural meaning, whereas –*ment* in *government* is less transparent).

The information in the orthographic buffer is then fed into two routes: the lexical and the sublexical routes. The lexical route allows for quick and accurate reading of known written words; the sublexical route allows reading letter strings that are not part of the lexicons (unfamiliar words or nonwords).

The lexical route starts with the orthographic input lexicon. This lexicon holds entries for words whose written form is known to the reader. It does not contain the meaning or sounds of the words, but it does contain pointers to these representations. This orthographic lexicon is organized by the written frequency of the words, and therefore accessing a more frequent word is faster. This means both that the identification of frequent words as words is faster and also that reading them aloud is faster (compared to words that have similar orthographic and phonological forms but lower frequencies).

To access the phonological form of a written word, the information then flows in the lexical route from the orthographic input lexicon to the phonological output lexicon. The phonological output lexicon holds the phonological information about the sounds of the spoken words the reader knows. It contains information about the consonants and vowels of the word, stress position, and number of syllables. The direct connection between the orthographic input lexicon and the phonological output lexicon allows the reader to make accurate conversion from a written word to its phonological form in a relatively fast way.

The final stage of the lexical route, which is shared with the sublexical route, is the phonological output buffer. This buffer is a phonological short term component that has two roles: holding the phonological information until it has been fully produced, and assembling units into larger units. The most straightforward units it assembles are the phonemes that arrive from the phonological output lexicon (or from the sublexical route). In this case, phonemes are assembled to create a word. But it is also responsible for assembling other types of building blocks: it unites affixes with their stems to reconstitute morphologically complex words, it assembles number words to create multi-digit numbers, and possibly also assembles syntactic phrases, including the function words within them (Dotan & Friedmann, 2015).

The lexical route also includes another branch, which connects the orthographic input lexicon to the conceptual-semantic system. This sub-

route allows for the comprehension of written words. The orthographic input lexicon activates the relevant entry in the semantic lexicon, which in turn activates the corresponding concept in the conceptual system. The conceptual system is the a-modal storage of concepts that allows not only for the comprehension of written words, but also for understanding pictures, objects, and heard words. The semantic lexicon is a storage of words, rather than concepts, in which words are organized by their semantic features. (According to some conceptualizations of this lexicon, it does not store words like other lexicons, but rather serves as a hub with pointers from each entry to its phonological, orthographic, and conceptual representations).

Whereas the lexical route is efficient and accurate in reading known words, it is helpless when it comes to words that do not exist in one of the lexicons. In this case, with non-existing words like "lexicof", a different path of reading aloud is required. This different path is provided by the sublexical route, in which reading proceeds via grapheme-to-phoneme conversion. Letters are parsed into graphemes, letters or groups of letters that are the written form of a phoneme. For example, the letters *s* and *h* in "shell" would be parsed as one grapheme, to be converted to a single phoneme, and the same with the double *l* in this word. After this parsing, grapheme-to-phoneme rules are applied sequentially (possibly with separate conversion of consonants and vowels), and the resulting phonemes are gathered in the phonological output buffer, and assembled there to create the full string of a nonword or a new word.

Skilled readers read via all these routes: reading aloud proceeds via the sublexical and lexical-phonological routes, and access to the conceptual-semantic system in the lexical-semantic sub-route is activated for comprehension. However, if the target is a known existing word, reading aloud via the lexical-phonological route is typically quicker than via the sublexical route, and hence the spoken word is principally the result of processing via the lexical route. When the target does not exist in the reader's lexicon, the word is read only via the sublexical route. When the word does exist in the orthographic and phonological lexica, but has low frequency, it will take time to activate its representation in these two lexica, and hence, it might be that it would be read in the same pace through the lexical and sublexical routes, in which case the buffer would have to deal with results of the two routes together. This would not be problematic when the two routes provide the same output, but when one provides a certain output and the other provides a different output, this may lead to a clash in the phonological output buffer, which may cause delay in reading aloud. This would be the case, for example, in a word like "castles", which the well-informed lexical route would read with a silent *t*, but the sublexical route would pronounce the *t*.

It seems that the semantic sub-route only partially participates in this party: it is used for comprehension, and for selecting the relevant reading of a heterophonic homograph in sentence context (as in "I shed some *tears* because I found some *tears* in my purple shirt") but it is not a natural route for reading aloud. As we will see below, it is used to read aloud only as a last resort, when there is no other available route.

Types of developmental dyslexia

Dyslexias are selective deficits in the various components of the reading model that we have just described, or in the connections between them. A deficit in each component or connection gives rise to a different pattern of reading difficulty, characterised by different error types and different words that pose most difficulty for the reader. Dyslexias are roughly divided into *peripheral dyslexias*, reading impairments that result from deficits in the orthographic-visual analysis stage, and *central dyslexias*, which are reading impairments in the later stages of the lexical and sublexical routes. We will start by describing the developmental peripheral dyslexias that are currently known, and then proceed to describe the developmental central dyslexias.

Letter position dyslexia

Encoding of the relative position of letters within the word is one of the functions of the early stage of reading, the orthographic-visual analyzer. Individuals who have a deficit in this function can still identify the letters correctly, but fail to encode the order of the letters within the word. This dyslexia is called *letter position dyslexia* (LPD), and its cardinal symptom is migrations of letters within words.

Developmental LPD has been reported for Hebrew, Arabic, English, and has also been identified in Italian and Turkish (for Hebrew: Friedmann, Dotan, & Rahamim, 2010; Friedmann & Gvion, 2005; Friedmann, Gvion, & Nisim, 2015; Friedmann & Rahamim, 2007, 2014; Keidar &

Friedmann, 2011; Khentov-Kraus & Friedmann, 2011; Arabic: Friedmann & Haddad-Hanna, 2012, 2014; English: Kohnen et al., 2012; Kezilas et al., 2014; Italian: Luzzatti et al., 2011; Turkish: Güven & Friedmann, 2014). In these languages, the main characteristics of LPD are similar: individuals with LPD tend to transpose letters within words, mainly the middle letters, whereas the first and final letters hardly ever lose their positions. Other properties of LPD are that migration errors occur with both consonants and vowel letters and in both root letters and affixes, and adjacent letters transpose more often than non-adjacent ones. Errors occur in both words and nonwords, and more errors occur when the target word (or nonword) is migratable, namely, when the letter position error creates an existing word. Thus, words like *cloud* (which can be read as "could"), *fried* (fired) and *dairy* (diary) are more difficult in LPD than *clown, cried,* and *fairy;* and nonwords like *talbe, setps,* and *snig* are harder than nonwords in which a transposition does not create a word. The probability of making a migration error is affected by the relative frequency of the target word and its migration counterpart: there is a higher probability that a child will read *loin* as "lion" than vice versa.

Consider what can account for the lexicality and frequency effects on migration rates in LPD: If the letter position information that arrives from the orthographic-visual analyzer is underspecified for the order of the middle letters, then the input to the orthographic input lexicon would activate an entry that is matching the partial information. In the case of a word like *form*, input that says: "f in the beginning, m in the end, and in the middle we have o and r in some order" would activate both *form* and *from*, and allow for a transposition error to occur. If the target word is *frog* it will only activate *frog*, as, regrettably, the word *forg* does not exist. A similar explanation holds for nonwords: when a nonword like *talbe* is presented, a visual analyser in which letter position encoding is impaired would provide the lexicon information of the identities of the letters, without information about the order of the middle letters. This would activate "table" in the orthographic input lexicon. In contrast, a non-migratable word like *nalbe* would not activate any word in the lexicon, and would hence be read via the sublexical route, which, being sequential, would stand a better chance of correct encoding of letter order. Explaining the effect of frequency follows a similar line: if the word *salt* arrives in the lexicon as "s in the beginning, t in the end, and in the middle a and l

in some order", because *salt* is much more frequent than *slat* (which means, before you run to your dictionary, a long, thin, flat piece of material), it will be accessed first, and the result will be correct reading (even though the letter positions were not encoded correctly). In contrast, when the word "slat" is presented, again the lexicon would retrieve the more frequent "salt", giving rise to a transposition error.

Another related type of error that individuals with LPD make is omission of doubled letters: for example, they may read *drivers* as "divers", and *baby* as "bay". To account for these errors in individuals with impaired letter position encoding, consider the two "r"s in *drivers*: they are identical in all properties except for their position within the word. Therefore, a person who cannot encode letter positions would be unable to distinguish between the two instances of *r*, and may omit one of them. Importantly, not all individuals who make transpositions in reading aloud, such as reading *skate* as "stake", have a reading deficit. Individuals with a deficit in the phonological output buffer may also produce somewhat similar errors when reading aloud. Thus, it is necessary to distinguish between these two possible sources of errors. Distinguishing between them can be done by testing reading without oral production, and testing word and nonword production in tasks that do not involve written input. If the deficit is indeed LPD, a problem in the early stage of reading input, it would also apply to reading tasks that do not involve spoken output but not to spoken output that does not involve reading. Conversely, individuals whose phonological output buffer is impaired would make errors in reading only when they read aloud, would not make errors in silent reading, and would make errors in speaking, even though this involves no written input. Thus, individuals with LPD perform well on word and nonword repetition and in other speech production tasks, and perform poorly on written lexical decision (is *forg* a word?), on written same-different decision task with migratable words (are the two words in the pair *clam - calm* the same?), on written word-to-picture matching (is the word *flies* related to a picture of flies or to a picture of files?), and on semantic matching between written words (is *trail* related to a court or to a hike?).

Studies of LPD have also found that text reading is not the best way to identify and diagnose LPD: take, for example, the sentence "Yogurt, feta cheese, and milk are dairy products" even if the letter position encoding

fails to encode the order of the letters in "dairy" correctly, semantic considerations may inhibit "diary" in this context, and boost the activation level of "dairy". And indeed, studies that tested migration errors in migratable words presented as single words and in text found that LPD participants make fewer errors when these words are embedded in text (Friedmann & Rahamim, 2007).

Another point relates to whether transpositions result from a general visual problem. In fact, many children with LPD receive the title "impaired eye convergence". Had it been a general visual problem, we would expect them to show the same difficulty in reading numbers and sequences of symbols. However, they do not. In fact, it is very rare to find a person with LPD who also makes migration errors in symbol sequences or numbers (Friedmann, Dotan, & Rahamim, 2010). LPD also does not stem from general attentional disorders. There are children and adults with severe selective attention difficulties whose reading is migration-free, and there are individuals with LPD with no attentional problems (Lukov et al., 2015). Relatedly, Ritalin (Methylphenidate), which is prescribed to individuals with attention disorders and reduces the symptoms of attention deficits in some, has no effect on migrations in reading (Keidar & Friedmann, 2011).

Once diagnosed, LPD can be efficiently treated. For example, Friedmann and Rahamim (2014) found that when children with LPD read while tracing the words letter-by-letter with their finger, the rate of migration errors they make is significantly reduced. Interestingly, colouring each letter in a different colour does not help and may even increase the number of migrations: in this case, the children not only need to bind two features— a letter to its position. They also need to bind another feature— colour— with the letter and with its position.

Knowing the characteristics of this dyslexia is crucial for diagnosing it (and consequently, for treating it efficiently). Without this knowledge, it is easy to miss this dyslexia in some languages. Take for instance the children with LPD reported by Kohnen et al. (2012): they experienced considerable difficulty in reading and their parents and / or teachers were concerned about their reading. However, standard reading tests that do not include migratable words failed to detect any difficulty, and classified them as normal readers. It was only once these children were asked to read migratable words – words in which migration of middle letters

creates another existing word, that their dyslexia was revealed and diagnosed, and consequently, treated.

This property of LPD, whereby middle-migratable words are the ones that expose the dyslexia gives rise to cross-linguistic differences in the liability of this dyslexia to be detected. In languages and orthographies in which there are many migratable words (as is the case in Hebrew, for example), LPD will be relatively easily noticed. In other languages, such as English, a special list of migratable words is needed to detect and diagnose it. Another property of orthographies that interacts with the manifestation of dyslexia in various orthographies is the existence of position-dependent allographs: in Arabic, for example, the same letter takes a different form in different positions within the word. This property has been shown to interact with LPD: letters almost never migrate when their migration would change their allograph (Friedmann & Haddad-Hanna, 2012). As a result, fewer letter position errors occur in Arabic than in, for example, Hebrew. For diagnosis purposes, this means that in these languages, migratable words in which migration does not change letter form should be presented.

Attentional dyslexia

A different type of letter migration occurs in a different type of dyslexia, attentional dyslexia. In this dyslexia, letters migrate between neighbouring words, but are correctly identified and keep their original relative position within the word. For example, the word pair *cane love* can be read as "lane love" or even "lane cove". Almost all migrations between words preserve the relative position of the migrating letter within the word so that, for example, the final letter in one word migrates into the same position, the final position, in the other word. This indicates that between-word position encoding can be impaired while within-word position encoding remains intact. This point can be seen also in the double dissociation that is found between LPD and attentional dyslexia: there are individuals with LPD without attentional dyslexia, who make letter migrations within words but not between words, and individuals who show the opposite pattern, with letters migrating between, but not within, words (Friedmann, Kerbel, & Shvimer, 2010; Friedmann & Rahamim, 2007; Lukov et al., 2015). Letter migrations between words occur both horizontally and vertically, namely, letters can migrate from a word that

is to the left or to the right or above or below the target word. So far, developmental attentional dyslexia has been reported in Hebrew, Arabic, and English (Friedmann, Kerbel, & Shvimer, 2010; Friedmann & Haddad-Hanna, 2014; Rayner et al., 1989), and it was also detected in Italian and Turkish.

As in LPD, the lexicality of the error response affects the probability that letters will migrate between words: migrations are more likely to occur in attentional dyslexia when the result of migration is an existing word, in both word and nonword pairs. Other effects relate to the length of the target word and to how similar the two words are: longer words are more liable to migrations between them, and words that differ in only one letter are less liable to migrations than words that differ in more letters. Different positions within the word have different susceptibility to between-word migrations: final letters migrate more than the other letters in the word, and more migrations occur from the first to the second word than vice versa.

Except for migrations between words in which a letter substitutes another letter in the same position in the other word (*light fate*->"fight late"), individuals with attentional dyslexia also make intrusion and elbowing errors, in which a letter migrates to the other word but the letter that has been in the same position in the other word stays. An example for intrusion is *light fate,* where the f migrates to the first position, without deleting the letter that was there, creating "flight late" (or "flight fate"). Letters may also migrate from a word that has recently been viewed and has already disappeared (although this happens to a lesser degree than the migrations from words still seen in the vicinity of the target word). Such "ghost" migrations may be caused by abnormal refresh of the representations of words in the orthographic buffer.

One other type of error that frequently occurs in attentional dyslexia is the omission of one of the instances of a letter that appeared in the same position in the two words (such as reading the word pair *clay plan* as "clay pan"). The reason attentional dyslexics make such omissions can be understood in a way similar to the omission of doubled letters in LPD. In the pair *clay plan*, for example, the only difference between the two *l*'s is the words they belong to. Otherwise, they are identical: they have the same abstract identity and the same within-word position. Individuals with attentional dyslexia fail to bind letters to words, and hence miss the only feature distinguishing between the two letters. Hence, they cannot know that there are two instances of *l,* and they may omit one (Friedmann, Kerbel, & Shvimer, 2010).

Interestingly, migrations between words were also reported in normal reading: already in 1977, Allport discovered that when skilled readers read two (or four) words in very short presentation times, followed by a graphemic mask, they usually manage to identify the letters and their relative position within the words, but still make errors of letter migrations between words (see also Shallice & McGill, 1978; Ellis & Marshall, 1978; Mozer, 1983; and McClelland, & Mozer, 1986). Whereas the phenomenon is superficially similar to the migrations we see in attentional dyslexia, the origins of these migrations are different: in attentional dyslexia they are the result of a failure in the orthographic-visual analyzer in letter-to-word binding, whereas in skilled reading they are the result of two words arriving together in the orthographic input lexicon, activating the letters of the two words, and therefore also words that are composed from these letters (Davis & Coltheart, 2002; Friedmann, Kerbel, & Shvimer, 2010; Shetreet & Friedmann, 2011).

Despite a tempting conclusion to be drawn from its name, attentional dyslexia, Like LPD, is not related to a general visuo-spatial attentional deficit. Individuals with attention deficits may show completely normal and migration-free reading, and individuals with attentional dyslexia may have no attention deficits (Lukov et al., 2015). And here too, Ritalin, which improves attention disorders symptoms in individuals with attention disorders, does not affect reading in attentional dyslexia and does not reduce between-word migrations (Keidar & Friedmann, 2011). These considerations makes the name Shallice & Warrington (1980) selected for this dyslexia slightly confusing (but considering how cumbersome "letter-to-word-binding dyslexia" is, the name remains).

This dyslexia is a wonderful example for how important it is to diagnose each individual with reading difficulties and identify the exact type of developmental dyslexia. Once we know that a child or an adult has trouble reading because "the letters on the page are jumping", as one of our patients defined it, helping them is straightforward. Given that the errors originate in neighboring words, once the other words in the area are covered, error rates are magically reduced. In a study of various treatment directions and manipulations on text presentation, Shvimer, Kerbel, &

Friedmann (2009) found that reading with a "reading window" – a piece of cardboard with a word-sized window cut in its middle – reduced the general rate of between- word errors in a group of individuals with developmental attentional dyslexia from 31% to 14%, and the rate of between-word migration was reduced from 13% to a mere 4% errors.

What are the predictions for the effect of different orthographies on the manifestation of developmental attentional dyslexia? Again - like in LPD - migratability and letter forms should play a crucial role in this dyslexia: in languages in which the orthographic and morphological structure create a high probability that between-word migration would create an existing word, attentional dyslexia will be more easily detected. If a language has different letter forms when the letters appear after different letters (as is the case in Arabic, for example), some migrations may be blocked, and as a result the between-word migrations rate would be reduced.

Letter identity dyslexia

Letter identity dyslexia is a deficit in the orthographic-visual analysis, in the function responsible for creating abstract letter identities. It is not a visual deficit, as readers with this dyslexia can still match similar non-orthographic forms, visually match two instances of the same letter in different sizes, and copy letters correctly. However, readers with letter identity dyslexia cannot access the abstract identity of letters from their visual form, so they cannot name a letter, identify a written letter according to its name or sound, or match letters in different cases (Aa). A detailed study of a boy with this type of dyslexia is presented in Brunsdon, Coltheart, and Nickels (2006). This failure to identify letters might result in incorrect identification of letters in isolation, in substitution or omissions of letters within words and nonwords, and in "don't know" responses.

Because of the scarcity of reports on this type of developmental dyslexia, it remains to be seen whether *associative visual letter agnosia* is the same type of dyslexia or a separate entity. Associative visual letter agnosia is a difficulty in identifying letters from sight, with preserved ability to identify letters from motion (moving the finger on the lines of the written letter) or touch (for example, holding and feeling the various sides of a plastic form of the letter or a letter-shaped cookie). It currently seems that

the main difference between letter agnosia and letter identity dyslexia is that letter agnosia only affects access from the visual modality into the orthographic-visual analyser, but abstract letter identity, if accessed through another modality, is preserved. Letter identity dyslexia, on the other hand, is a specific deficit in abstract letter identity.

Neglect dyslexia

Neglect dyslexia has gained considerable attention in the literature of acquired dyslexia, where it has been thoroughly studied with a large number of individuals in several languages (see Vallar, Burani, & Arduino, 2010 for a review). Developmental left neglect dyslexia has been reported only in Hebrew (Friedmann & Nachman-Katz, 2004; Nachman-Katz & Friedmann, 2007, 2008, 2009, 2010) and Arabic (Friedmann & Haddad-Hanna, 2014). Developmental right neglect dyslexia has been identified in Turkish (Güven & Friedmann, 2014).

Hemi-spatial neglect relates to the phenomenon of difficulty to report or attend to stimuli on one side of the visual field, typically, the left side. Neglect dyslexia refers to a similar difficulty in reading. Several types of neglect dyslexia are known from the literature on acquired neglect dyslexia. One classification refers to the level at which the neglect occurs: at the word level, where letters on the neglected side are omitted, substituted, or added, and at the sentence or text level, where whole words on the neglected side are omitted. It seems that neglect dyslexia at the sentence or text level is part of the effects of visuo-spatial neglect (Haywood & Coltheart, 2001), whereas neglect dyslexia at the word level may be an orthographic-specific deficit, independent of general visuo-spatial attention. Neglect dyslexia is further classified by the side that is neglected, with far more occurrences of left neglect than right neglect.

The only pattern that has been described so far for developmental neglect dyslexia is neglect dyslexia at the word level (neglexia). Readers with neglect dyslexia at the word level neglect one side of the word, typically the left side. Neglecting one side of a word results in omissions, substitutions, or additions of letters on that side of the word, which occur more frequently when the result is an existing word. Because this deficit is at the early, prelexical stage, written word comprehension and lexical decision on written nonwords are affected by neglexia (so that *rice* may be taken to be frozen water, and *gice* may be judged as an existing word).

Developmental neglexia can be orthographic-specific, affecting only letter strings but not symbol strings, and even not number sequences. A dramatic demonstration of the selectivity if neglexia to orthographic material was provided by Friedmann and Nachman-Katz (2008): they presented to children with neglexia sequences in leet characters (Perea, Duñabeitia, & Carreiras, 2008), i.e., characters that can be perceived either as numbers or as letters: For example, 7109179 in Hebrew is "professor"; 816 8055 can be read in English, with some effort, as "big boss". The children with neglexia made neglect errors when instructed to read the word list, but when the same list of stimuli was presented with the instruction "please read these numbers", they made almost no neglect errors.

Data from acquired neglexia indicate that the neglected side of the word is more sensitive to neglect errors when it is part of an affix, and is almost never omitted when it is part of the base or root (Reznick & Friedmann, 2009). It is still unknown if readers with developmental neglexia, whose reading acquisition is marred by their neglexia, develop the normal morphological abilities necessary for morphological decomposition. If they do, they might show the same morphological effect as individuals with acquired neglexia on neglect errors.

Once developmental neglect dyslexia is identified, it can be treated effectively. Nachman-Katz and Friedmann (2010) evaluated different treatment directions, and found that manipulations on the text that attract attention to the left of the word may reduce neglect errors in reading considerably. The group of 20 participants with developmental neglexia who made 42% neglect errors in reading words without any manipulation made only 20% such errors when they traced the word letter-by letter with their left hand index finger, 23% neglect errors when they tapped with their left finger to the left of the word, 27% when a small blinking lamp was placed to the left of the word they read, and 28% when a coloured vertical line was placed to the left of the word. Vertical presentation of the target words and presentation of the word with a double space between the letters were also useful, reducing error rates from 42% in normal presentation to 30% and 21%, respectively.

Such effects on reading can also assist the distinction between errors on the left that result from limitation of the orthographic input buffer and neglexia. Vertical presentation, tapping with the finger to the left of the

word and adding symbols to the left of the word should not affect the reading of a reader with a limited buffer, but do affect reading in neglexia. The way reading in neglexia may interact with orthography relates, like the dyslexias we described before, to the chances that a relevant error would create an existing word. Thus, languages with dense orthographic neighbourhoods, in which substitution, omission, or addition of letters on the left of the word has a high probability of creating another existing word would give rise to more neglect errors. The reading direction also affects the manifestation of neglexia, as in languages read from left to right, left neglexia would affect the beginning of words, and in right-to-left languages it would affect their ends. Reading direction may also affect the rate of errors in another way: if, as is typically the case, shifting of attention to the left is impaired, reading in right-to-left orthographies may be more impaired than reading in left-to-right ones.

Visual dyslexia/ orthographic input buffer dyslexia

Visual dyslexia was originally defined, in Marshall and Newcombe's (1973) article and later, as a deficit in the orthographic-visual analysis stage that causes reading the target word as a visually similar word, with errors of substitutions, omissions, migrations, and additions of letters. Marshall and Newcombe themselves said that "There are, no doubt, subtypes of visual dyslexia corresponding to the specific nature of the visual impairment". And indeed, there are. As we have seen already, there are other types of dyslexia that result from selective deficits in the orthographic-visual analyser and present specific types of errors (such as letter position errors in LPD, between-word migrations in attentional dyslexia, letter substitutions in letter identity dyslexia), we suggest that a reading impairment should be classified as visual dyslexia only if it cannot be accounted for by a specific deficit in the orthographic-visual analyser such as letter position dyslexia, attentional dyslexia, letter identity dyslexia, or neglexia.

Visual dyslexia, which is distinct from these other impairments of the orthographic-visual analyser, is a deficit in the output of the orthographic-visual analyser. As a result, this dyslexia affects all functions of the orthographic-visual analyser: letter identification, letter position within the word, and letter-to-word binding. Therefore, it involves letter identity errors and letter migrations within and between words.

Distinguishing between visual dyslexia and a selective impairment in each of the functions of the orthographic-visual analyser is easy: visual dyslexia can be distinguished from letter identity dyslexia in that letter identity dyslexia only involves letter substitutions and omissions, but not letter migrations within and between words. Similarly, visual dyslexia can be distinguished from LPD (it involves also letter substitutions and omissions, and letter migrations between words, and not just letter migrations within words), from attentional dyslexia (as it involves also letter substitutions and omissions and letter migrations within words, and not just between-word migrations), and from neglexia (errors occur on all sides of the word, not only on one side).

A somewhat harder task is to distinguish between visual dyslexia and an impairment that affects several functions of the orthographic-visual analyser together. There are not many reports of this type of developmental dyslexia, but it seems that the pattern of errors is slightly different: unlike in LPD, migrations within words in visual dyslexia occur in exterior letters as well as in middle letters (visual dyslexia will see errors like was-saw, letter position dyslexia will not).

Furthermore, it is still an open question whether visual dyslexia and graphemic buffer dyslexia are the same dyslexia. Graphemic buffer dyslexia is characterized by all types of errors that we described above for visual dyslexia, it is affected by length, with significantly more errors in longer than in shorter words, and morphological affixes show increased vulnerability: when presented with a morphologically complex word, individuals with graphemic buffer dyslexia often keep the base or the root and omit or substitute the morphological affixes (Sternberg & Friedmann, 2007, 2009). It is also the case that whereas they make letter substitutions and omissions in reading words (and nonwords), they identify single letters correctly.

Like in cases of transposition within and between words, when an individual makes errors that are typical for visual dyslexia or graphemic buffer dyslexia, it is important to make sure that the errors indeed result from an input deficit and do not result from a phonological output deficit. To do so, one should look at reading without oral output and spoken production without written input.

Surface dyslexias

So far, we have described dyslexias that result from an impairment in the orthographic-visual analysis stage. We now move to describe central developmental dyslexias: impairments in later stages of reading, in the lexical and sublexical routes.

Surface dyslexia is a deficit in the lexical route, which forces the reader to read aloud via the sublexical route, though grapheme-to-phoneme conversion. Reading through grapheme-to-phoneme conversion instead of through the lexical route causes several types of problems in reading. Firstly, individuals with surface dyslexia make regularisation errors in reading aloud. This is evident in their reading of irregular words such as *stomach, receipt, or comb,* which include a silent letter, or a letter that is converted to a phoneme that is different from the phoneme that the grapheme-to-phoneme conversion rules dictate. Surface dyslexia may also affect their reading of words that allow for ambiguous conversion to phonology, such as *bear* (which may be read via the grapheme-to-phoneme conversion route as "beer"). Words that have ambiguous conversion typically include ambi-phonic graphemes that can be converted in two or more ways into phonemes. Such words are mainly problematic in surface dyslexia when the ambi-phonic graphemes are converted, in the specific word, into the less frequent phoneme (like the letter *i*, which is pronounced one way in *kid* and another way in *kind*). Sublexical reading may also be problematic in words with more than one syllable in languages in which stress is lexically determined and not marked orthographically, and in languages in which not all vowels are specified in the orthography, as is the case in Hebrew and Arabic.

The accurate oral reading of such irregular and unpredictable words requires access to lexical, word-specific knowledge. Such information is stored in the lexical route, in the orthographic input lexicon, so when reading aloud via this lexicon is impossible, these words are liable to be read incorrectly. In contrast, regular words for which there is only one possible reading via the sublexical route, which leads to the correct pronunciation, are read correctly, even if they are infrequent.

Individuals who have pure surface dyslexia, where only the lexical route is impaired, have intact sublexical route, and they are therefore able to read nonwords normally (see Castles, Bates, & Coltheart, 2006, for a discussion of the notion of pure dyslexias).

Surface dyslexia affects not only the accuracy of reading aloud: at least for some individuals with surface dyslexia, those whose orthographic input lexicon is impaired, comprehension is also affected. Consider how comprehension can be achieved via the sublexical route. Take for example the written form *taksi*: this is probably not an entry in your orthographic input lexicon, but you can nevertheless understand it. The way in which the comprehension of such items proceeds is via the sublexical route, which generates a nonword in the phonological output buffer based on grapheme-to-phoneme conversion. The phoneme sequence in the phonological output buffer is then produced in inner speech and thus can access the conceptual-semantic system through the phonological input components, the phonological input buffer and the phonological input lexicon. This is the route that individuals with surface dyslexia use to understand words they read that they cannot recognize orthographically: orthographic-visual analyser, grapheme-to-phoneme conversion, phonological output buffer, phonological input buffer, phonological input lexicon, semantic lexicon, conceptual system. Now, this long and winding road could achieve correct comprehension of words like *dog* or *paper*, but would be dubious once the word is homophonic. Consider, for example, reading a homophonic word like "wail". Individuals who read it via the sublexical route and then understand it through the input phonological route would not be able to distinguish *wail* from *whale* and hence have difficulties understanding such homophones. Similarly, *which* and *witch*, which sound the same when read via the sublexical route, can only be distinguished on the basis of their separate entries in the orthographic input lexicon, so an individual with an impaired orthographic input lexicon would not be able to distinguish between them.

A class of words that are specifically difficult for readers with surface dyslexia are words that, when read via the grapheme-to-phoneme conversion route, can result in another existing word. We call these words "*potentiophones*". Especially adults with developmental surface dyslexia develop a tendency to monitor their production and try to produce only existing words. This tendency may also be supported by feedback from the phonological output lexicon, which is only provided to responses that are words that exist in the phonological output lexicon. This strategy is definitely useful for avoiding errors in reading words like *listen, sword,*

stomach, build, and *door*, but what about words like *bear, now,* and *none*? In these cases, reading via the sublexical route might end up with other existing words that sound like "beer", "know", and "known".

Finally, beside the problems in accuracy and in comprehension, surface dyslexia results in slower-than-normal reading. Even in cases in which reading via the sublexical route results in an accurate oral reading of the word, as is the case with words like *sport, dog,* and *mark,* the process of sequentially converting each letter into its corresponding phoneme in the sublexical route is slower than reading the whole word via the lexical route (Spinelli et al., 1997; Zoccolotti et al., 1999).

Surface dyslexia is defined as a deficit in the lexical route. The lexical route is a multi-component route, and a deficit in each of these components or in the connections between them can yield surface dyslexia. Importantly, whereas all the deficits in the lexical route result in reading aloud via the sublexical route and hence in inaccurate and slow reading aloud, each of these deficits gives rise to a different pattern of surface dyslexia (Friedmann & Lukov, 2008). Let's consider the possible loci of deficit in the lexical route that would cause a reader to read aloud via the sublexical route: one is the orthographic input lexicon (or the access to it from the orthographic-visual analyser). In this case, not only reading aloud would be affected but also lexical decision of pseudohomophones (the reader will have difficulty determining whether *anser* is a word or not). They will also have difficulties in the comprehension of homophones and potentiophones (and hence will not know whether *whether* is a question word or something that has to do with rain and temperature). Another possibility is that the orthographic input lexicon itself is intact, but its output connections to the semantic lexicon and the phonological output lexicon is impaired. In this case, lexical decision will be fine but comprehension of homophones will be impaired. Another possible type of surface dyslexia is the interlexical surface dyslexia, where the connection between the orthographic input lexicon and the phonological output lexicon is impaired. In this case both lexical decision and homophone comprehension will be fine, and only reading aloud would be affected. Finally, a deficit in the phonological output lexicon would also force the reader to read aloud via the sublexical route but no problems are expected in lexical decision or homophone comprehension. In the case of phonological output lexicon deficit, word

production is impaired not only in the context of reading, but also in naming and in spontaneous speech.

These different types of surface dyslexia dictate different treatment approaches. In the case of interlexical surface dyslexia, it would probably be enough to recommend to the child to stop reading aloud (and to his teachers to stop asking him to read aloud). When the orthographic input lexicon itself is impaired, one may work on filling the lexicon by repeated exposure to words, by intensive reading (a recommendation that most children with developmental dyslexia do not like to hear), and by linking the written form of the word with its phonological form (for example, looking at the book while a parent is reading and pointing to the word they read while uttering it). Alongside the attempts to rehabilitate the impaired lexical route, treatment can also aim to strengthen the grapheme-to-phoneme conversion rules, including the second tier (multiletter) rules and explicit teaching of morphological orthographic rules.

The properties of surface dyslexia, indicating its sensitivity to homophonicity and regularity, dictate its interactions with various orthographies: Languages with no homophonic letters have better chances of being read correctly, even via the sublexical route. In contrast, readers with surface dyslexia who read languages with many degrees of freedom in reading via the sublexical route: ambi-phonous letters, underrepresentation of vowels and stress pattern, and silent letters are liable to make many more errors in reading. In languages with predictable grapheme-to-phoneme conversion like Italian, it is often stress position and reading rate that are the most sensitive markers for surface dyslexia (Zoccolotti et al., 1999).

Phonological dyslexias

Phonological dyslexia is the mirror image of surface dyslexia: here, the sublexical route is impaired, and reading can only proceed via the lexical route. The defining symptom of phonological dyslexia is the difficulty in reading nonwords, which appears alongside correct reading of words that are stored in the orthographic input lexicon.

Individuals with phonological dyslexia cannot read new words, only words that are already in their orthographic input lexicon (and phonological output lexicon). As one can imagine, this may pose a critical problem for children who have this dyslexia before they begin reading: in their case – every written word is a new word, and no word can be read through the lexical route. These individuals with developmental phonological dyslexia take much longer to learn to read. They usually start mastering reading in second or third grade, when they start having enough whole words in the orthographic input lexicon to allow them to read. They usually encounter this severe difficulty again when they learn to read in a new language.

Such pattern is a result of a deficit in the sublexical route, and it can result from impairments at various points in this route. The most basic type of phonological dyslexia (though it seems not to be the most frequent type) is a deficit in the conversion of single letters into phonemes. Such impairment would be evident not only in reading nonwords, but also when single letters are presented. Individuals with this type of phonological dyslexia, *letter-to-phoneme conversion phonological dyslexia*, fail even when they try to sound out single letters.

A different type of phonological dyslexia, *multiletter phonological dyslexia*, involves the more complex rules of conversion, which apply to more than a single letter. Such multiletter or context-sensitive rules in English would be for example the rule that dictates how to pronounce the "sh" in *ship* and the "ch" in *chip;* the rule that dictates the way *a* is pronounced in *mate*, which is different from the way it is pronounced in *mat;* and the way the pronunciation of *c* is affected by the following letter, as in *city* and *cell* versus *care, core, and cure*. Multiletter phonological dyslexia does not affect the pronunciation of single letters, but can be detected when multiletter graphemes are read. Such multiletter deficit can either result from a deficient parsing of letters into multiletter graphemes or from a deficient conversion of multiletter graphemes (or letters within certain multi-letter contexts) into phonemes. These two sources for multiletter phonological dyslexia may be very difficult to discern, especially in the case of developmental dyslexia (see Marshall & Newcombe, 1973 for a description of letter-to-phoneme conversion and multiletter phonological dyslexias).

Yet another type of phonological dyslexia, which is a relatively frequent one, is a deficit that does not affect the conversion itself but rather the next stage, in which the phonemes that are the products of the conversion are stored for a short time and assembled into a whole word or a nonword

(see e.g., Temple & Marshall, 1983; and Campbell & Butterworth, 1985, for case studies of two young women with developmental phonological dyslexia that probably resulted from such a deficit). The component that is responsible for receiving the output of the conversion, blending it and holding it until its production is complete, is the phonological output buffer. In the case of phonological-output-buffer-phonological-dyslexia, no errors are expected in reading single letters or single graphemes. The deficit shows a clear length effect, with longer words and nonwords showing more errors than shorter ones. This type of phonological dyslexia affects nonwords more gravely than words because whereas words can get boosted by activation from the phonological output lexicon, nonwords cannot. Thus, for example, reading aloud of a long nonword such as *elomatod* may crash and give rise to omissions, substitutions, and transpositions of some of the phonemes, but the same reader may still read correctly *elevator*, a word with the same structure and the same number of phonemes. This is because once these phonemes arrive at the phonological output buffer, they activate the corresponding entry in the phonological output lexicon, which, in turn, resonates and reciprocates by adding activation to the existing word (see the double-sided arrow in Figure 1).

Because the phonological output buffer is responsible not only for assembling phonemes of nonwords, but also for assembling morphologically complex words, individuals with phonological output buffer phonological dyslexia often show a deficit in reading morphologically complex words, often omitting or substituting the non-base morphemes. Importantly, because the phonological output buffer is part of the speech production system, and not only responsible for reading, individuals with phonological buffer dyslexia show difficulties with long nonwords and morphologically complex words not only when they read them, but also when they repeat or spontaneously say them (Dotan & Friedmann, 2015).[1]

Therefore, to distinguish between the different types of phonological dyslexia and understand why a child has difficulties reading nonwords, one should not only ask the child to read words and nonwords but also

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[1] In some languages and in some cases, several responses are possible readings of a nonword: this is the case with a nonword like *knuint* in English, and with most nonwords in which the vowels are not fully specified in languages like Hebrew and Arabic. In these cases, any of the possible conversions would count as correct reading of the nonword, whereas consonant substitutions and omissions that violate grapheme-to-phoneme conversion rules, for example, would count as incorrect reading.

test single letter reading, multiletter rule knowledge, and repetition of long nonwords,.

Treatment of the different types of phonological dyslexia should be different: for conversion phonological dyslexia, treatment should focus on explicit teaching of letter-to-phoneme conversion rules. For multi-letter phonological dyslexia, treatment should focus on explicit teaching of multi-letter conversion rules. Individuals with phonological output buffer dyslexia, on the other hand, may benefit from breaking the target word into smaller units, such as syllables or consonant-vowel units, when reading.

Vowel letter dyslexia

The sublexical route can also be affected selectively. Vowel dyslexia results from a specific deficit in the sublexical route that selectively impairs the way the sublexical route processes vowels (Khentov-Kraus & Friedmann, 2011). Individuals with vowel dyslexia omit, substitute, transpose, and add vowel letters. Thus, the word *bit* can be read as "bat", "but" or even "boat". These errors occur in reading, without parallel errors in speech production, and they affect vowel *letters* rather than vowel phonemes.

Because it is a deficit in the sublexical route, individuals whose only dyslexia is vowel dyslexia have difficulties only when they read nonwords and new words, but they can still read correctly via the lexical route. If, however, the reader has both vowel dyslexia and surface dyslexia, then he will be forced to read even existing words via the sublexical route, and will therefore make vowel errors also in real words. This developmental dyslexia has been reported so far for Hebrew, Arabic, Italian, and Turkish, and it occurs more frequently in words in which a vowel letter error results in an existing word. As a result it is more prominent in orthographies that allow for vowel letter omissions or transpositions, such as Hebrew and Arabic, in which words can include sequences of consonants, and in orthographies with dense orthographic neighbourhoods.

We discussed before the interaction between letter form and letter position errors: in letter position dyslexia, letter transpositions do not occur if they change letter forms. The story is different in the case of vowel dyslexia, as it affects a stage that is beyond the orthographic-visual

analyser: in both Hebrew and Arabic, an error in the grapheme-to-phoneme conversion that places a vowel in an incorrect position, occurs at a stage that is no longer sensitive to the form of the letter, and vowel errors can occur even when they cause a change in letter form.

Additional selective deficits in converting certain features in the sublexical route have been reported for acquired dyslexia, and have been witnessed also in developmental cases, but not yet reported in detail. Such dyslexias are for example the selective deficit in the voicing feature (dyzlegzia, Gvion & Friedmann, 2010), and a deficit in the nasality feature (nasalexia, Gvion & Friedmann, 2012)

Deep dyslexia

The main characteristic of deep dyslexia, which is its defining feature, is the production of semantic errors in reading, such as reading the written word *lime* as "lemon" or "sour". Other error types that are common in deep dyslexia are morphological (reading *played* as "play", *birds* as "bird", and *smiles* as "smiling"), and visual errors (*clay* as "play", *owl* as "own" and *gum* as "game"). Cases of developmental deep dyslexia have been reported by Johnston (1983), Siegel (1985), Stuart and Howard (1995), and Temple (1988, 1997) for English, and by Friedmann and Haddad-Hanna (2014) for Arabic.

Within the dual route model, this reading pattern was interpreted as multiple lesions in both the sublexical grapheme-to-phoneme conversion route and in the direct lexical route between the orthographic input lexicon and the phonological output lexicon, which force the reader to read via meaning (Ellis & Young, 1988).

This double deficit gives rise to grading of difficulty of various types of words. Basically, words that can be read correctly via their meaning (possibly via visual imagery of the target word) would be the words that are most accurately read by individuals with deep dyslexia. Reading of nonwords, on the other hand, is very severely impaired. When children with deep dyslexia are asked to read nonwords, they either declare that they cannot read these words or lexicalise them – reading them as similar existing words (reading *diger* as "tiger", for example). Other words that are difficult to imagine, such as function words and abstract words are also affected. When asked to read function words, individuals with deep dyslexia substitute the target word for another function word, substitute it

with a visually similar concrete word, or just say that these are words they cannot read. For the same reason, imageability plays a crucial role in reading accuracy in this dyslexia, with imageable and concrete words being read better than abstract words (Coltheart, 1980; Coltheart, Patterson, & Marshall, 1987; Marshall & Newcombe, 1973).

Morphologically complex words are also very difficult to read in this developmental dyslexia, and individuals with this dyslexia substitute or omit morphological affixes when they read morphologically complex words. This could be a result of the imageability effect (try to visually imagine *smiled*. The –ed just vanishes in the process), and it could also result from the process of reading in this dyslexia. Recall that words in the lexicons are represented by their bases, stems or roots, whereas the morphological affixes may be read through a direct route from the orthographic input buffer to the phonological output buffer. If this is the case, and the direct route is impaired, reading of affixes can be severely compromised, whereas the bases can be read better.

This type of dyslexia is especially difficult in its developmental form, because filling the orthographic lexicon and establishing its connection to the phonological output lexicon and the conceptual-semantic system are very difficult given that the deficit in the sublexical route and between the lexicons is present in the time of reading acquisition. A further difficulty relates to the fact that as in acquired deep dyslexia, individuals with developmental deep dyslexia often also show syntactic deficits, and hence, find it harder to rely on sentence context to read words correctly.

Several points of interaction are imaginable between developmental deep dyslexia and the orthography that the reader reads in. Given the specific difficulty in morphologically complex words, languages in which words are more morphologically complex are expected to be more difficult to read. Another interesting interaction was reported in the case of diglossic languages. In Arabic, for example, the situation is that the spoken language is different from the written, standard language in all respects: syntactically, lexically, morphologically, and phonologically. As a result, reading via naming, in which a child sees a word, understands it, and then names it based on its meaning or visual image, creates a situation in which words written in standard Arabic are read in the spoken vernacular (for example, the developmental deep dyslexic boy FA, reported in Friedmann and Haddad-Hanna, 2014, read the standard Arabic word *dar*, house, as

"'bet", its spoken counterpart, and *tabib*, a medical doctor in Standard Arabic, as "daktor".

Access to semantics dyslexia

Dyslexia can also appear in a somewhat surprising form, whereby reading is fluent and accurate. This is the case of access to semantics dyslexia, sometimes termed "direct dyslexia". Individuals with this dyslexia can read aloud all kinds of words, including irregular words, low frequency words, function words, and morphologically complex words. They can also read nonwords and new words accurately. However, they cannot understand written words, even those they can read aloud correctly. The correct reading aloud indicates that the lexical route between the orthographic input lexicon and the phonological output lexicon is preserved in these individuals and so is the sublexical route (Castles, Crichton, & Prior, 2010). This pattern can stem either from a deficit in the access from the orthographic input lexicon to the semantic lexicon or from a deficit in the conceptual/semantic system itself. If the deficit is in the conceptual/semantic system, either in the semantic lexicon or in the conceptual system, we would probably not call it dyslexia, but rather a semantic deficit. In this case, these individuals would also have trouble understanding words they hear, and not only words they read. A semantic deficit would also involve impairments in speech production, with semantic errors, in the case of a semantic lexicon impairment, or unrelated words, in the case of a deficit in the conceptual system (Howard & Gatehouse, 2006; Nickels, 1995, 1997; Nickels & Howard, 1994; Friedmann, Biran, & Dotan, 2013).

A deficit that is more specific to reading, and that would more comfortably fit into the label "dyslexia", is a disconnection between the orthographic input lexicon and the semantic lexicon. Such deficit does not affect reading aloud of single words or nonwords, and does not affect the comprehension of heard words or the production of words. It does, however, affect the comprehension of written words. If the reader does not understand the words he reads, this may also cause incorrect prosody in reading sentences aloud, and also incorrect reading aloud of heterophonic homographs. Think, for example, about reading a sentence like "I shed some *tears* because I found some *tears* in my purple shirt" – access to semantics is required in order to select the correct reading of

each heterophonic homograph and hence, such sentences are expected to be read incorrectly in semantic access dyslexia.

Clearly, such dyslexia can result in what educators call "reading comprehension difficulties" – when comprehension of single written words fail, one can be sure that the comprehension of sentences and texts would fail as well. Notice, however, the opposite is not true: not all children who have problems in the comprehension of sentences and text have semantic access dyslexia. In fact, in most cases it is their syntactic ability that is impaired, causing impaired comprehension of the sentences with complex syntactic structures (Friedmann & Novogrodsky, 2007; Szterman & Friedmann, 2014). Limited vocabulary can also give rise to reading comprehension difficulties, and so do general attention deficits that prevent the readers from focusing on the text they are reading.

One final note: whereas some researchers call this dyslexia "hyperlexia", we do not recommend using this term. After all, it is not that reading is too good in these individuals; it is their comprehension that is too poor.

A note about the relative frequencies of the various types of developmental dyslexia

As we have seen, different types of dyslexia have different properties. Specifically, they are sensitive to different aspects of the presented stimuli. Letter position dyslexia, for example, is manifested mainly in migratable words, namely, words in which a letter position error creates another existing word. Individuals with attentional dyslexia make errors only when several words are presented together. Individuals with surface dyslexia make errors on words that, when read via the sublexical route, can be read in several ways, and are most prone to make errors on words that, when read via grapheme-to-phoneme conversion, can create other existing words. Individuals with phonological output buffer dyslexia can read existing short words well, but have difficulties reading long words, nonwords, and morphologically complex words, etc.

This has far-reaching implications for the diagnosis of the various types of dyslexia: if the relevant stimuli for a certain type of dyslexia are not presented, this dyslexia can be missed. A test without migratable words may miss letter position dyslexia, a test that only presents single words in isolation (or word pairs that do not allow for letters that migrate between them to create other existing words) may miss attentional dyslexia, a test

with only regular words may miss surface dyslexia, and a test with short existing words will miss phonological buffer dyslexia. Additionally, if only reading rate is scored but not error types, certain dyslexias will be missed and it will be impossible to detect them, and, given that reading rate can only yield the distinction between slow and quick, there will be no way to detect the 19 types of dyslexia.

(Additionally, slow reading rate does not necessarily indicate dyslexia, as it can result from various general cognitive problems, from attentional difficulties, articulation problems, and more). The current situation is that most standard tests do not include the relevant stimuli to detect all kinds of dyslexia, and are therefore not sensitive to many of the dyslexia types. Typically, they include regular and irregular words, and nonwords. This would allow for the detection of surface dyslexia and phonological dyslexia (without identifying the specific subtypes of these dyslexias), but not the other types of dyslexia. As a result, we usually do not know how frequent the other types of dyslexia are, and this makes it impossible to make any statements about the relative incidences of the different forms of developmental dyslexia.

We do have some insights from Hebrew, where a test that is sensitive to the various types of dyslexia, including the peripheral ones (Tiltan, Friedmann & Gvion, 2003), has been administered in the past 15 years, and some data has accumulated as to the relative frequency of the various types of dyslexia in Hebrew. An analysis of the reading of 224 individuals with developmental dyslexia showed that the two most frequent dyslexias in Hebrew are surface dyslexia and letter position dyslexia, followed by vowel letter dyslexia and attentional dyslexia.

A recent study (Lukov et al., 2014) that tested the attentional abilities and dissociations between attention disorders and dyslexias reported on 83 participants with dyslexia who were tested with the Tiltan battery, and their types of dyslexia were identified accordingly and reported. They showed a similar distribution, where letter position dyslexia is the most frequent dyslexia, followed by and surface dyslexia, vowel letter dyslexia, and attentional dyslexia. To know more about the distribution of types of dyslexia in other languages, tests that are sensitive to the various types of dyslexia should be developed and administered to a large number of participants with dyslexia.

Conclusion

The classification of types of developmental dyslexia has theoretical, as well as clinical and educational implications.

One of the most important theoretical implications regards the source of developmental dyslexia. When one considers the multi-faceted nature of developmental dyslexia, and the fact that impairments in different components of the reading process give rise to dyslexias with completely different properties and error types, it becomes evident that one source cannot account for all kinds of developmental dyslexia. Therefore, dyslexia cannot be a deficit in phonological abilities (as claimed by, e.g., Snowling, 1998, but see Coltheart & Jackson, 1998, in the same dyslexia forum), because many types of dyslexia are unrelated to phonology. Examining the various types of dyslexia, one can see that only dyslexias that affect the phonological stages, predominantly certain types of phonological dyslexia, may be related to phonology (see Blomert & Willems, 2010; Castles & Coltheart, 2004, and Castles & Friedmann, 2014, for discussions of this hypothesis). Similarly, dyslexia does not necessarily come with a lexical retrieval deficit (cf. Wolf & Bowers, 1999, for a review). Surface dyslexia that arises from a deficit in the phonological output lexicon does, but most other dyslexias, such as those that result from a deficit in the orthographic-visual analyser, and even other subtypes of surface dyslexia (see Zoccolotti et al., 1999; Friedmann & Lukov, 2008), do not. It is also impossible to determine that developmental dyslexia is a visual deficit (e.g., Stein & Walsh, 1997; Bosse et al., 2007), for two reasons – one is that not all dyslexias result from an orthographic-visual analyzer impairment. Phonological and surface dyslexias, for example, do not. Namely, whereas visual impairments can impede reading, not all dyslexias result from visual impairments. Moreover, even the dyslexias that result from an orthographic-visual analyzer impairment do not result from a visual or attentional impairment. It is often the case that the impairment is selective to orthographic material and does not apply to reading numbers and symbol sequences (Friedmann et al., 2010; Lukov et al., 2015).

Another theoretical contribution of the study of types of dyslexia is its contribution to understanding the cognitive model of reading. The interaction between neuropsychology of reading impairment and the characterization of the reading process is fruitful for both sides. For

example, identifying the selective deficit in vowel reading in the sublexical route sheds light on the grapheme-to-phoneme conversion process, suggesting a separate treatment for vowel and consonant letters. In the other direction, letter position dyslexia was identified because the cognitive reading model assumed a letter position encoding function to exist and the prediction for a selective deficit in letter position encoding drove the search for individuals with such a dyslexia.

Finally, the different sources of the various types of dyslexia dictate different treatment directions and different approaches for reading instruction to each of them. Reading with a reading window strikingly improves reading in attentional dyslexia, but does not affect reading in surface dyslexia, deep dyslexia, phonological dyslexia, or letter position dyslexia. Silent reading is a recommended path for individuals with interlexical surface dyslexia but not for those whose surface dyslexia results from a deficit in the orthographic input lexicon. Knowing the different ways the reading process can break down and understanding the properties of each type of dyslexia allows the development and application of focused treatment directions that are tailored to the specific errors and source of each type of developmental dyslexia.

Louis Pasteur once remarked "In the fields of <u>observation</u> chance favors only the prepared <u>mind</u>." This is nowhere truer than in the study of developmental dyslexia. In discussing his reported cases of developmental dyslexia, Hinshelwood (1900) observed "I have but little doubt that these are by no means so rare as the absence of recorded cases would lead us to infer. Their rarity is, I think, accounted for by the fact that when they do occur they are not recognised. It is a matter of the highest importance to recognise the cause and the true nature of this difficulty in learning to read which is experienced by these children, otherwise they may be harshly treated as imbeciles or incorrigibles and either neglected or flogged for a defect for which they are in no wise responsible. The recognition of the true character of the difficulty will lead the parents and teachers of these children to deal with them in the proper way, not by harsh and severe treatment, but by attempting to overcome the difficulty by patient and persistent training."

With a mind prepared to identify and diagnose the various types of developmental dyslexia that we already know, and to detect new types of dyslexia that can result from impairments in the reading process that we

have not encountered yet, we will be able to help such children and adults with developmental dyslexia, as well as advance the theoretical knowledge in this field.

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