Word count: 10,757 words

Cognitive profile of students with dyslexia entering postsecondary education

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Abstract. Internationally, an increase in the numbers of students with dyslexia in higher education is noticeable. Consequently, more and more information has been collected on the cognitive profile of these students compared to their non-disabled peers. In this chapter an overview is provided on the cognitive functioning of this group of students and the implications these characteristics may have on their academic functioning. Furthermore, this review provides a theoretical framework for the optimization of guidance protocols for students with dyslexia in higher education.

Keywords: dyslexia, higher education, cognitive profile

Introduction

Dyslexia

Literacy is a mean of identification, understanding, interpretation, creation, and communication in an increasingly digital, text-mediated, information-rich and fast-changing world. It is a fundamental human rightand the foundation for lifelong learning. It is fully essential to social and human development in its ability to transform lives.(UNESCO, 2016)

Reading (and writing) is embedded in all aspects of life. In the current socio-economic setting of developed countries literacy is considered an automated skill in adulthood requiring little to no effort. In work-related settings reading fluency is essential for obvious reasons but even in our personal lives, not being able to read fluently has its pitfalls. In this continuously evolving technological society the focus on written communication has grown tremendously over the past few decades. Think of the World Wide Web, smartphones, Facebook, and tablets and it instantly becomes clear that literacy leads to greater participation in social and economic life. As such, not being able to read fluently is not a visible handicap but does influence one’s quality of life.

The UNESCO Institute for Statistics (UIS) provides us with literacy data, indicating that up to 750 million adults still cannot read or write a simple sentence. A positive evolution is that 50 years ago, 22% of people between the ages of 15 and 24 lacked basic literacy skills compared to 9% today, and young people in Africa and Asia, in particular, are far more likely to be literate than they were half a century ago, (UNESCO, 2017).

According to Ardila et al. (2010) low literacy can stem from social or personal reasons. Social reasons are, for instance, poverty or absence from school, while personal reasons relate to learning difficulties, mental retardation, significant motor and/or sensory problems or other deficiencies resulting in a failure to learn to read despite an adequate schooling and educational environment. These two types of causes have different cognitive consequences, making it crucial for researchers to make a clear distinction between them.

In this chapter, we will describe a very specific subgroup of individuals who struggle with the basic skills of learning to read and write despite normal intelligence, adequate schooling and the absence of any motor or sensory deficits that could explain the deficit. We refer to this specific reading disability with the term dyslexia, which sets itself apart from reading disabilities stemming from educational, social or other external or internal factors that can explain the low literacy. They are students entering higher education (HE) with an assessment of developmental dyslexia, hereafter referred to as dyslexia.

Dyslexia is a specific learning disability characterized by a cluster of symptoms that result in people having difficulties with specific language skills, particularly reading and spelling. At present, dyslexia is a widely known disorder which has received a lot of attention from researchers all over the world. Initially, the scientific community focused on dyslexia in primary school children, as this is the time the literacy problems first present themselves. Subsequently, researchers expanded their area of interest to the identification of precursors of dyslexia in toddlers and the implications of being dyslexic in secondary school. Thanks to the extensive research performed on these populations, early detection, diagnosis, and remediation and guidance programs have much improved in the last few decades. It is partly due to this increase in knowledge and in the effectiveness of treatment programs that adolescents perform better in secondary school. In addition, the implementation of more extensive support measures in HE have led to a decrease of the impact dyslexia has on academic performance. According to Vogel et al. (1998) dyslexic students now have aspirations and expectations that go beyond secondary school. Their self-advocacy and self-knowledge have increased, leading to more effective planning. All these factors have facilitated transition to higher education (HE).

Dyslexia in higher education

The numbers speak for themselves. Studies from all over the world report an increase in the number of students with dyslexia, registering for a program in higher education. Not because more students are diagnosed with dyslexia, but due to a larger inflow of high school graduates in bachelor programs. Numbers from the international literature (Callens, Tops, & Brysbaert, 2012; Hadjikakou & Hartas, 2008; Hatcher, Snowling, & Griffiths, 2002; Madriaga et al., 2010; Olofsson, Taube, & Ahl, 2015) demonstrate this global trend. While dyslexia is most commonly diagnosed during childhood, it has been shown that despite adequate intensive remedial teaching, dyslexia continues to have an impact later in life.

Higher education is no longer compulsory. So, individuals with dyslexia entering higher education are likely to be a very specific, highly motivated subgroup with possibly less severe symptoms. Still, the context of higher education is very different from secondary school, with a higher work load, more written materials to be processed, course materials in foreign languages, and students required to manage their own time. For individuals with dyslexia, this new environment may pose additional challenges, the more because dyslexia has been reported to affect other cognitive skills as well, which could have an effect on academic performance.

In a qualitative study, Defranc (2008) interviewed university students with dyslexia regarding the specific problems they encountered in their studies. First, compared to their peers, these students reported needing more time to read and structure their courses, because comprehension was hampered by the time they had to invest in the technical aspect of reading. Second, course materials provided in a non-native language formed an extra obstacle. Third, the students encountered difficulties with taking notes in classes, in particular in unstructured classes and noisy surroundings. Note taking is a very complex skill with a heavy load on working memory and is affected by several factors such as listening comprehension, information processing, writing and organization skills. Fourth, paper and essay writing was perceived as extra problematic because of difficulties in formulating ideas and identifying errors (grammatical, spelling) in proofreading. Fifth, memorizing facts and names were found to be difficult. Finally, problems with time management due to a poor concept of time or the inability to estimate how long tasks will take were perceived as an extra cause of stress.

The findings of Defranc (2008) are in line with those reported by Du Prez, Gilroy, and Miles (2008), McLoughlin, Leather, and Stringer (2003), and Mortimore and Crozier (2006). It goes without saying that because of their cognitive deficits and the reported problems, students with dyslexia in higher education are potentially more burdened than the average student. Therefore, gaining insight into the cognitive functioning and the specific strengths and weaknesses of these students is essential to guarantee maximal support in their academic career, giving them optimal chances of succeeding.

Making precise estimates of prevalence of dyslexia in higher education is not easy. Even for the prevalence of dyslexia in the general population, numbers vary substantially. This is to a large extent caused by the fact that language proficiency is a continuous variable and that definitions used to describe the impairment are based on different cut-off scores (Ghesquiere, Boets, Gadeyne, & Vandewalle, 2012; Ziegler & Goswami, 2005). Prevalence numbers up to 20% have been reported. However, prevalence rates of 5 to 10% are more commonly accepted (Jimenez, Guzman, Rodriguez, & Artiles, 2009; Lewis, Hitch, & Walker, 1994; Plume &

Warnke, 2007; Snowling, 2000). For the presence of dyslexia in higher education, numbers are even less clear. Few accurate and reliable data are at hand to describe the proportion of dyslexic students within the general bachelor population. The Flemish Educational Council published a report in 2006 with the following information. They cited a Dutch study by Broeninck and Gorter (2001) in which 2 to 3% of all students in a sample of 478,000 appeared to be dyslexic. In the academic year 2003-2004, 5.4% of the students had a functional impairment, of which 2.2% reported a learning disability (dyslexia and others). In the UK, approximately 3.2% of all students are diagnosed with dyslexia (Warmington, Stothard, & Snowling, 2012). However, not only are these numbers somewhat outdated but they are also rough estimates not based on systematic testing.

There are other reasons to see the above figures as rough approximations. First, the rates are likely to differ between fields of study. Experience has told us that because of the language relatedness of their disability, dyslexic students are more inclined to register for more technical programs and are therefore more represented in some degrees than in others (Kleijnen & Loerts, 2006). Second, the criteria for entering higher education may have an effect as well. A system with high entrance criteria results in a strong selection of individuals, possibly leading to smaller proportions of students with dyslexia in higher education programs. Finally, because there are no regulations requiring students to reveal their disability, part of the population may remain undetected.

Because of the increasing presence of students with dyslexia in higher education, researchers started to address the topic and studies were set up to explore the phenomenon. At first, information was limited, but currently quite some data have been gathered, so that we can begin to help these students.

Studies on dyslexia in higher education

The first studies mainly came from the US and the UK. However, one should be cautious about generalizing these findings to other languages and educational settings. First, there is the fact that languages differ in the complexity of the transcription from phonology to orthography and the other way around. English is one of the more opaque languages in this respect (compare the words *tough* and *though*, *have* and *gave*, *mint* and *pint*, etc.). Many languages are more transparent, with more one-to-one correspondences between letters and sounds. The inconsistencies in the letter-sound-correspondences have been related to the rate at which children learn to read and write and also to the prevalence of reading and writing disorders (Ziegler & Goswami, 2005). Second, the Anglo-Saxon education model differs from that in many other countries, as it is based on the master-apprentice model where somewhat more stringent selection criteria are applied. To get into college or university application forms need to be handed in and selection criteria based on high school grades are applied. .. Also, tuition fees are much higher in the Anglo-Saxon education model than in countries. As a result, the student populations in both educational settings may be different.

To examine the situation in a specific country in Continental Europe, we set up a large-scale study to chart the cognitive profile of dyslexic students in this educational system and in a language (Dutch) that is considerably more transparent than English (Callens et al., 2012). Performance was measured on a multitude of tests related to reading, spelling, phonology, math, memory, speed of processing and intelligence. In addition, we compared sufficiently large groups of first-year bachelor students with dyslexia (N=100) and controls (N=100) matched on gender, socio-economic status, and field of study. As you will see below, the results of our study were very comparable to those obtained in English (as summarized in a meta-analysis by Swanson and Hsieh, 2009), indicating that the cognitive profile of students with dyslexia is comparable across the (Western) world.

Below, we summarize the findings and compare it to previous research. We do not claim that the information presented is exhaustive. A selection of cognitive skills has been made based on the prevalence in the literature and their relevance for academic performance within the context of higher education. Readers who are interested in the details are referred to Callens et al. (2012), Tops, Callens, Lammertyn, Van Hees, and Brysbaert (2012b),Tops, Callens, Bijn, and Brysbaert (2012a), Tops, Callens, Van Cauwenberghe, Adriaens, and Brysbaert (2013a), Tops, Verguts, Callens, and Brysbaert (2013b), Callens, Tops, Stevens, and Brysbaert (2014), and Tops, Callens, Desoete, Stevens, and Brysbaert (2014).

Cognitive skills in dyslexia

Word reading and spelling

Problems with word reading and spelling remain the core deficit of students with dyslexia in higher education. Even for these students we see little improvement in those basic skills (see also (Vellutino, Fletcher, Snowling, & Scanlon, 2004). This is surprising, as one would expect high functioning individuals entering higher education to have compensated for those deficiencies (Snowling, 2000).

Impaired accuracy in whole-word reading and text reading was found by Lindgren and Laine (2011). A meta-analysis conducted by Swanson (2012) also identified single-word recognition as the main characteristic (*d* = 1.37) of adults with dyslexia. Although some variation is observed between languages, effect sizes for word reading vary between 1 and 2 (i.e., a difference of 2 standard deviations, a very noticeable differences in performance between students with and without dyslexia).

The research strongly suggests that the reading problem is related to speed rather than accuracy. It is best measured with a simple one-minute word reading test, in which participants have to read aloud a series of unrelated words as fast and accurately as possible. The dependent variable is the number of words correctly read in one minute. No better discriminatory power is obtained if the test involves sentences or texts. The deficiency in reading even becomes less pronounced in text reading (see below), possibly because the text context supports decoding through top-down processing. Students with dyslexia also demonstrate substantial problems with non-word reading (Callens et al., 2012; Hatcher et al., 2002; Reid, Szczerbinski, Iskierka-Kasperek, & Hansen, 2007; Suarez-Coalla & Cuetos, 2015; Warmington et al., 2012), but these are not more pronounced than in word reading.

Apart from a much slower reading speed, spelling is the second core problem in adult individuals with dyslexia in higher education. This time, the dependent variable is accuracy rather than speed. Word spelling accuracy is highly discriminative in all languages (Hatcher et al., 2002; Lindgren & Laine, 2011; Wilson & Lesaux, 2001) and no further gains in power are achieved if the spelling test involves sentences rather than words. These findings are based on dictation tasks which are focused on the spelling abilities themselves. In everyday writing, such as essay writing or written exams, the focus lies more on discourse. Performance in spontaneous writing will be discussed later in the chapter.

Phonological processing

In addition to word reading and spelling errors, dyslexic students in higher education continue to have difficulties with phonological processing. The broad category of phonological processing includes *phonological awareness*, *phonological working memory,* and *lexical retrieval*.

Phonological awareness is the awareness of the sound structure of a language and the ability to consciously analyze and manipulate this structure. There is a large consensus in the literature that students with dyslexia show deficiencies in phonological awareness compared to proficient readers, on more demanding phonological tasks such as spoonerism or reversals (Bruck, 1992; Wilson & Lesaux, 2001; Wolff, 2009). In our study, students with dyslexia showed an effect size of d = 1.5 on a spoonerism task, a test of phonological awareness which simply involved exchanging the first sounds of two words (e.g., turning ‘‘Terry Wogan’’ into ‘‘Werry Togan’’) (Perin, 1983). As is the case for word reading, the effect is mostly situated in the speed with which the task could be performed (Callens et al., 2012; Hatcher et al., 2002; Warmington et al., 2012; Wilson & Lesaux, 2001; Wolff & Lundberg, 2003). The deficit in phonological awareness has been linked to anatomical characteristics of the brain (for a review see Richlan, Kronbichler, & Wimmer, 2011). When we looked at the effectiveness of a battery of over 50 tests to predict dyslexia, we observed that no further gains in predictive power were obtained after three tests were entered into the model: word reading, word spelling and phonological awareness (spoonerism). This allowed us to have a prediction accuracy of 91 % (Tops et al., 2012b).

Phonological working memory involves storing phoneme information in a temporary, short-term memory store. Individuals in HE with dyslexia have a smaller phonological short term memory (PSTM) store than matched control students (Callens et al., 2012; Cavalli et al., 2016;

Parrila, Georgiou, & Corkett, 2007; Suarez-Coalla & Cuetos, 2015). Results are quite consistent on this matter. Usually phonological short term memory capacity is evaluated using nonword repetition. Speed seems to be more affected (d = 1.4) than accuracy (0.7 < d < 1.1).

Lexical retrieval is the ability to recall serially presented stimuli and is usually assessed using rapid automatized naming (RAN) tasks (e.g., rapid naming of letters and numbers) (Wagner & Torgesen, 1987). Performance on RAN tasks is said to reflect the ability to retrieve phonological codes from long-term memory and, therefore, the level of performance is seen as an expression of phonological processing. In our study, lexical retrieval as measured with rapid automatized naming (RAN) was slower in students with dyslexia in HE, as was reported by other researchers (Lervag & Hulme, 2009; Manis, Doi, & Bhadha, 2000; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007). In particular, the naming of letters and digits was slowed down (d = 1.0). Studies further suggest that continuous presentation versions of the RAN are more strongly related to reading fluency than discreet versions (Bowers & Swanson, 1991). In continuous versions, the stimuli are presented together on a sheet of paper or a computer screen; in discrete versions, the stimuli are presented one after the other. The superior discrimination power of continuous versions could be because dyslexics have more difficulties inhibiting previously activated information and processing upcoming items (lateral inhibition or crowding). It could also be related to the need of well-coordinated eye movements in the continuous versions. Still, there is good evidence that both discrete and continuous versions discriminate between groups of dyslexic readers and normal readers in HE.

The observation that a distinction can be made between alphanumerical (digits and letters) and non-alphanumerical (e.g. objects and colors) RAN tasks is of further interest. Each seems to contribute differently to reading (Savage & Frederickson, 2005) and they are thought to reflect differences in the cognitive sub-processes needed for successful task performance. Van den Bos, Zijlstra, and Van den Broeck (2003) reported that color and picture naming formed a single factor from the start of learning to read while letter and digit naming initially were separate constructs, which only became a single, stable factor from the age of 10 on. The distinction between the two types of stimuli is also seen in students with dyslexia. In most studies, dyslexic students are clearly slower than their normally functioning peers on alphanumerical RAN task; the group difference is more subtle for non-alphanumerical items (Callens et al., 2012; Hatcher et al., 2002; Reid et al., 2007; Suarez-Coalla & Cuetos, 2015; Warmington et al., 2012).

Intelligence

An often-used theoretical framework for human intelligence is the Cattell-Horn-Carroll theory of cognitive abilities. This hierarchical model subdivides intelligence into 70 specific abilities at the lowest level, eight primary abilities at the second level, and an overall g-ability or general intelligence at the third level. Contemporary intelligence batteries most often focus on the second level. They include fluid reasoning or fluid intelligence (Gf), comprehension-knowledge or crystallized intelligence (Gc), auditory processing (Ga), visual- spatial ability (Gv), long-term storage and retrieval (Glr), cognitive processing speed (Gs), short-term memory (Gsm), and quantitative reasoning (Gq) (McGrew, 2009). Unfortunately, not every intelligence test uses this three stratum model. So, results are sometimes difficult to compare. In this section, we will only reflect on fluid and crystalized intelligence in relation to dyslexia.

Fluid intelligence is the capacity to reason, and to solve novel and abstract problems, independent of learning, experience, and education. It is the ability to analyze new problems, identify patterns and relationships that underpin these problems and their extrapolation using logic. In line with other studies (Callens et al., 2012; Hatcher et al., 2002; Lindgren & Laine, 2011; Morgan, Sullivan, Darden, & Gregg, 1997; Reid et al., 2007; Suarez-Coalla & Cuetos, 2015), we failed to observe any difference in fluid intelligence between students with dyslexia and controls. Both groups perform at the same level on this aspect of cognitive functioning.

Crystallized intelligence relies on knowledge and skills acquired over a lifetime and the ability to retrieve this information from memory. It is highly influenced by formal education as demonstrated by differences in people's vocabulary and general knowledge. In our study, we observed a small difference in favor of controls on the crystalized subtests of the Kaufman Adolescent and Adult Intelligence Test (KAIT) with an effect size of d = .5. An effect size of the same order was reported by Swanson and Hsieh (2009) in their meta-analysis on cognitive functioning in adult dyslexic readers. In contrast, Morgan et al. (1997) and Reid et al. (2007) reported no difference.

Vocabulary

An aspect of crystalized intelligence that is of particular interest is vocabulary size. For most forms of human communication words are essential. We use words to read, write and talk. Vocabulary also has an influence on the development of other cognitive skills such as general language skills in children, and reading abilities and reading comprehension in both children and adults (Braze, Tabor, Shankweiler, & Mencl, 2007; Lee, 2011; Ransby & Swanson, 2003). Vice versa, reading experience is an important factor in vocabulary development (Perfetti & Hart, 2002). So the relationship between reading and vocabulary can go in both ways. Individuals with dyslexia have a tendency to avoid reading, are therefore are less exposed to print, potentially leading to problems in vocabulary acquisition.

A distinction is sometimes made between vocabulary breadth and vocabulary depth (Ouellette & Shaw, 2014). Vocabulary breadth refers to the number of letter strings known as words and therefore relates to the quantitative aspect of vocabulary knowledge. One way to measure it, is to ask participants to indicate which stimuli are words in a list of words and nonwords. Another way is to ask participants to match words to images, as is the case in the often used Peabody Picture Vocabulary Test (Dunn & Dunn, 2007). Vocabulary depth, on the other hand, refers to the extent of word meaning knowledge and relates to the qualitative dimension of vocabulary knowledge. It is measured with tasks that require the participants to produce the definition of words, as in the vocabulary subtest of the Wechsler Adult Intelligence Scales (Wechsler, 2012). Such tasks allow researchers to gauge the accuracy and degree of detail of word knowledge.

In line with the data on crystalized intelligence, we found that students with dyslexia in higher education were inferior (d = .7) to controls both on vocabulary breadth and depth (see also Swanson & Hsieh, 2009). In this meta-analysis by Swanson and Hsieh (2009), an effect size of $d = 0.71$ was reported for the category that grouped measures related to word meaning and semantic word knowledge (i.e., Peabody Vocabulary Test, WAIS vocabulary, and the Stanford Binet Vocabulary Test). Others, however, have failed to find a difference (Cavalli et al., 2016; Trainin & Swanson, 2005; Trecy, Steve, & Martine, 2013). Cavalli et al. (2016) even reported better performance of dyslexics on a vocabulary depth task, which they interpreted as a way in which dyslexic students in HE compensate for their deficiency in phonological skills. According to these authors, high-performing students with dyslexia learn to recognize words directly via spelling-meaning activation instead of indirectly through phonological mediation.

Speed of processing

Another relevant cognitive skill is the ability to rapidly perform cognitive tasks, also referred to as speed of processing. In studies that measure this component, speed of processing is usually operationalized as the number of visual elements that can be processed per second. Students with dyslexia tend to demonstrate deficits in perceptual speed of processing. Hatcher et al. (2002) found dyslexic students to be slower in speed of processing (d = 0.9) as measured with a digit copying task. In a paper by Stenneken et al. (2011), a group of high achieving young adults with dyslexia showed a striking reduction in perceptual processing speed (by 26%) compared to controls. In our own study, using a digit crossing task, we found an effect size of d = 0.6. Beidas, Khateb, and Breznitz (2013) even reported an effect size of d = 1.5 but a composite score was calculated using the Digit Symbol Coding and the Symbol Search Test of the Wechsler Adult Intelligence Scale (Wechsler, 2012), which also includes a strong short-term memory component.

It is not clear how speed of processing relates to the other variables. In a factor analysis of our test battery (Callens et al., 2014), the data of the digit crossing task were not part of the reading-related or intelligence-related factors, but of the mathematics-related factor. In addition, its loading was low. Further research seems to be needed here. In addition, the findings mentioned above mainly concern the speed of perceptual processing. Breznitz (2003) postulated a more domain-general speed of processing deficit in dyslexic readers. According to her, reading problems may arise mainly due to an "asynchrony" between the speed of processing in the visual versus the auditory system.

Short term memory and working memory

Both short term memory (STM) and working memory (WM) problems have been linked to dyslexia, both in children and adults. Based on theoretical models of memory, STM and WM should be viewed as overlapping yet distinguishable cognitive functions (Baddeley, 2000). However, STM and WM are often used interchangeably so the literature is sometime blurred by the ambiguous use of the terminology and the tasks used to measure the constructs. For clarity, we will refer to STM as the capacity to hold a small amount of sensory information in mind in an active, readily available state for a brief period of time (Aben, Stapert, & Blokland, 2012). Working memory is said to be a system involved in temporary storage, processing, maintenance, and integration of information from a variety of sources. It consists of a central executive that controls attention and oversees three components: the phonological loop (which deals with phonologically based information), the visuo-spatial sketchpad (visual and spatial information), and the episodic buffer (time-limited integration of information) (Baddeley, 2000). Tasks used to measure STM are usually simple span tasks. Here participants are required to maintain a series of symbols, elements or spatial positions over a brief period of time. In complex span tasks, used to measure WM, a demanding secondary task is added to the simple span task. So, they measure the ability to remember information while processing other information. Another task sometimes used to measure WM is a STM span task in which the elements must be remembered in a different order (e.g., in reverse order or in alphabetical order).

Working memory is thought to be involved in a range of cognitive functions going from reasoning to verbal comprehension. In an academic context, it is for instance used in tasks such as note taking. Low WM capacity is likely to impede performance; on the other hand, a high WM capacity could act as a compensatory mechanism for other deficiencies (Swanson, 2012).

In our study visual STM, verbal STM and verbal WM were slightly worse in students with dyslexia than in their peers (STM $d \approx 0.3$; WM $d = 0.4$). Beidas et al. (2013) also reported inferior performance on both verbal and visual working memory, except for auditory non-verbal working memory. These results are in line with Smith-Spark and Fisk (2007) who observed that both simple and complex span (in the visual and verbal modality) were impaired in university students with dyslexia. On the other hand, Alloway, Wootan, and Deane (2014), and Lockiewicz, Bogdanowicz, and Bogdanowicz (2014) found no differences between the groups.

The readers may have noticed that there seems to be an inconsistency between fluid intelligence (no difference between dyslexics and controls) and working memory / speed of processing (a small to medium difference), given that these concepts are interrelated (Conway, Kane, & Engle, 2003; Fry & Hale, 1996). This is clearly a gap in our knowledge that needs to be addressed with a battery of good tests.

Visuo-spatial ability

Visuo-spatial ability is the capacity to understand and reason about objects in space. In higher education this ability is essential for success in many fields of study, such as mathematics, natural sciences, engineering, meteorology and architecture. It has been suggested that high-functioning individuals with dyslexia may have superior visuospatial abilities. In the popular press, for instance, individuals with dyslexia are sometime presented as people who think in pictures. These assumptions are based on few empirical data, however.

The subtest Block design of the WAIS (Wechsler, 2012) is often used as a measure of spatial ability. On this task students with dyslexia in higher education do not differ from other non-disabled peers (Beidas et al., 2013; Callens et al., 2012; Collis, Kohnen, & Kinoshita, 2013; Warmington et al., 2012). When other tasks are used to measure visuospatial ability, findings are less clear, possibly because many of these studies had low power and involved many comparisons (which is known to lead to increased chances of false positives). When students are asked to perform mental rotation tasks on 2D and 3D images, most often no difference is found between groups in the behavioral data (Lockiewicz et al., 2014; Olulade, Gilger, Talavage, Hynd, & McAteer, 2012). However, differences have been reported in an fMRI study, where students with dyslexia showed atypical brain activation patterns when performing spatial rotation tasks (Olulade et al., 2012). In one study this was limited to female dyslexics (Winner et al., 2001); in another, dyslexic women performed worse, whereas dyslexic men performed better than controls (Brunswick, Martin, & Marzano, 2010). All in all, there is not much empirical evidence for a spatial superiority in dyslexia. Most studies point to equivalent visuospatial abilities in HE students with dyslexia and controls.

Arithmetic

When it comes to number processing skills in dyslexia, the most often reported –and examined- problems are those with mental calculation or arithmetic. Even for dyslexic students in higher education who are said to be a high functioning subgroup, problems have been reported (Callens et al., 2012; Hatcher et al., 2002; Swanson & Hsieh, 2009). We obtained effect sizes around d = 1.0.

According to the Triple code model (Dehaene, Piazza, Pinel, & Cohen, 2003) three codes underlie the ability to process numbers and become numerate. There is a visual code for Arabic digits mainly used for multi-digit calculation. The second code is an analogue number magnitude code used in number comparison, number estimation and approximate arithmetic. Finally, a verbal-phonological code is used for counting. The last code is used in verbally mediated arithmetic tasks when the answers are retrieved from memory (e.g., in multiplication). The most likely candidate for the reported arithmetic problems is the verbal code.

Gobel and Snowling (2010) found that HE students with dyslexia were slower in arithmetic operations, but not in number comparison tasks, in line with the predictions from the triple code model. Mathematical skills have been examined more closely in children with dyslexia. In this group number fact retrieval, multi-step arithmetic problem solving, and multi-digit calculation, where found to be inferior but approximate arithmetic and conceptual understanding (i.e., place value, calculation principles) were equal to the controls (Traff & Passolunghi, 2015), again consistent with the Triple code model.

Reading comprehension

Reading not only involves single word recognition. The end goal is comprehension of the messages conveyed in the text. An influential model of reading comprehension is the “Simple View of Reading” (Gough & Tunmer, 1986). Basically, it argues that reading comprehension depends on linguistic comprehension or the ability to understand oral language on the one hand, and the decoding of written information or word-deciphering ability on the other. Linguistic comprehension is shared with auditory comprehension and involves factors such as vocabulary knowledge, grammatical understanding, and discourse comprehension. Written word encoding refers to the fluency and accuracy with which visual words can be read. Problems in visual word recognition create a bottleneck that hinders the higher levels of processing, thus comprising linguistic comprehension.

An interesting question is whether HE students with dyslexia only have visual word encoding problems or whether their linguistic comprehension is affected as well. One way to assess this is to present stimuli in auditory form and look whether students with dyslexia perform on par with controls.

In our study, reading comprehension was slightly impaired in the dyslexia group using a text presented both visually and auditorily. The effect size was much smaller than that for visual word recognition, however (d = .5). In addition, when we looked more closely at the results, the difference between the groups was mainly due to performance on questions asking for factual information (d = .7), which rely heavily on phonological and verbal memory. For inference questions, which rely more on oral comprehension and interpretation, the scores did not differ between the groups. The study by Simmons and Singleton (2000) reported the opposite. Students with dyslexia tended to perform better on literal questions than on inferential questions. Many studies have reported equal reading comprehension levels for students with dyslexia and their peers with no reading difficulties (Jackson, 2005; Miller-Shaul, 2005), especially when time restrictions are removed (Lindgren & Laine, 2011; Parrila et al., 2007) or when students are allowed to consult the text while they are answering the questions (Lindgren & Laine, 2011). These small adjustments in reading comprehension measurements seem to reduce the impact of persistent reading deficits, while on timed evaluations the difficulties seem to persist (Kirby, Silvestri, Allingham, Parrila, & La Fave, 2008). Pedersen, Fusaroli, Lauridsen, and Parrila (2016) suggest that students with dyslexia tend to focus their attention to either word decoding or reading comprehension. Combining both subcomponents of efficient reading seem to demanding for this group.

All in all, it looks like reading comprehension in students with dyslexia is mainly compromised by their poor visual word encoding skills and slightly deficient verbal memory. When compensation is offered (auditory presentation of text, removal of time limits, having the text at hand), students with dyslexia seem to demonstrate equal text reading comprehension to their peers.

Writing

Just as reading comprehension involves more than individual word recognition, text writing is more than the correct spelling of words. Even more in higher education than in primary and secondary school, essays and written reports form the basis of evaluations and assessments. Struggling with essay writing is one of the most frequently reported problems in higher education students, both with and without dyslexia (Connelly, Campbell, MacLean, & Barnes, 2006; Farmer, Riddick, & Sterling, 2002; McLoughlin et al., 2003).
Unfortunately – considering the importance – not much research has been devoted to the performance in essay writing of HE students with dyslexia. Additionally, the studies that are available are not easy to compare due to differences in methodology for collecting the written materials, going from timed essay writing to the factual reproduction of studied answers in exams. This diversity reflects the diversity of test forms in HE, but it makes that the information on each form is limited. Below we discuss the most important findings.

Berninger and Amtmann (2003) formulated the Simple View of Writing, according to which writing involves the translation of ideas in verbal messages (shared with speaking) and the transcription of sounds, words, sentences and passages into print. The latter involves spelling and handwriting. The Not-so-simple model by Berninger, Garcia, and Abbott (2009) is somewhat more extensive, including executive functions and memory components as essential in writing.

Spelling. As we have seen above, individuals with dyslexia, even at the level of higher education, have major problems with word spelling. Indeed, in our study word spelling was the task with the highest difference between students with and without dyslexia. Even within the context of essay writing, students in HE with dyslexia clearly produce more spelling errors than their peers (Bogdanowicz, Lockiewicz, Bogdanowicz, & Pachalska, 2014; Gregg, Coleman, Davis, & Chalk, 2007; Tops et al., 2013a; Warmington et al., 2012). Tops et al. (2013a) reported effect sizes of d = 0.9 for morpho-syntactic errors and d = 0.5 for memory-related spelling errors in a task where participants were asked to write a precis of a one-page text. Compared to the effect sizes for word spelling (d = 2.0) and sentence spelling (d = 2.1) in the same group, differences seem less pronounced in spontaneous writing (see also Warmington et al. (2012), possibly because participants can avoid words of which they do not know the spelling.

An exception to the above conclusion is reported by Connelly et al. (2006). They found that students with dyslexia produced more spelling errors in essay writing than could be expected on the basis of their word spelling skills. Possibly, task differences caused this divergence. Whereas in the study of Tops et al. (2013a) participants were asked to write a summary of a simple text they had read before, Connelly et al. (2006) asked their students to write an essay on politics without preparation. Maybe the topic imposed a more complex word use. Another possibility is that on the spot essay writing requires more WM resources, which is more taxing for students with dyslexia than for controls.

As for the correct use of punctuation, relatively few studies have examined this particular aspect of writing and the available results are contradictory. Bogdanowicz et al. (2014) and Farmer et al. (2002) did not find differences, whereas other studies reported a small effect size

(Connelly et al., 2006; Tops et al., 2013a). It should be noted, however, that Farmer et al. (2002) tested a small sample of participants, so that only large effect sizes could be identified.

Handwriting. The second component of transcription is handwriting. Two aspects are involved: quality and fluency. The neatness of handwriting influences the evaluation of texts (Defrancq & Van Laecke, 2009). Raters have a tendency to give lower scores to texts and even exams written in a sloppy handwriting (Briggs, 1970, 1980). So, handwriting quality may affect assessment scores in higher education. Studies comparing handwriting quality of students in HE with and without dyslexia must use raters who are unware of the manipulation and who are asked to assess the handwriting without looking at the contents of the text or the spelling. The few studies that did so, found no differences between HE students with and without dyslexia (Gregg, 2007; Tops et al., 2013a).

On the other hand, students with dyslexia do appear to have a disadvantage when it comes to the fluency of writing, the ability to produce a number of lexical units within a limited time interval. Connelly et al. (2006), Warmington et al. (2012) and Callens et al. (2012) all compared the fluency in handwriting between a group of dyslexic adolescents in higher education and a group of non-disabled peers using very different methods. In the study by Connelly et al. (2006), participants were asked to write as many letters of the alphabet as possible within one minute. In the second and third study a 13-word sentence had to be copied as many times as possible within two minutes. In all three studies the dyslexic students were at a disadvantage. In Hatcher et al. (2002) writing speed ($d = 1.2$) was even among the four variables that predicted the presence of dyslexia with a 95% accuracy rate.

*Text quality.*t is clear that HE students with dyslexia are at a disadvantage on the transcription part. The question is whether this also affects their ability to translate ideas into coherent messages. One way in which this could happen, is that spelling and handwriting require more WM resources, leaving less resources for text planning.

To examine the issue properly, all texts must be transcribed so that they no longer differ in the quality of spelling (and in handwriting). Quantitative analyses of such transcriptions reveal few differences between students with dyslexia and without dyslexia. Compared to their non-disabled peers, students with dyslexia tend to use shorter words (Greg et al., 2007; Tops et al., 2013a) but the manuscripts of both groups do not differ on other measures such as average sentence length, type token ratio, and the total number of sentences written (Connelly et al., 2006; Gregg et al., 2007; Tops et al., 2013a). With respect to lexical diversity (number of different words used) and total word count, the results are less clear and point to small effect sizes, if present (Bogdanowicz et al., 2014; Connelly et al., 2006; Gregg, Coleman, Stennett, & Davis, 2002; Gregg et al., 2007; Tops et al., 2013a).

Another way to measure the quality of text content is to ask readers (blind to the condition) how good the texts are. Tops et al. (2013a) asked teachers from the final years of secondary education to judge the quality of texts produced by students with and without dyslexia (all texts rendered without spelling errors in a uniform way with Microsoft Word). The average quality given for the summaries of students with dyslexia (4.9 out of 10) was slightly lower than that of the controls participants (5.7; effect size: d = .4). Comparable results can be found in Gregg et al. (2002), Gregg et al. (2007), Hatcher et al. (2002) and Tops et al. (2013a) . Instruction has been proven helpful for improving text planning (Therrien, Hughes, Kapelski, &

Mokhtari, 2009; Woods-Groves, Therrien, Hua, & Hendrickson, 2013), so this looks like a promising avenue for help that can be given to HE students with dyslexia.

Conclusions and practical implications

Justification for compensatory means

In light of the rising number of students with dyslexia in higher education, having an overview of the cognitive strengths and weaknesses associated with dyslexia is worthwhile. Clearly, these students are confronted with a range of challenges that make studying harder for them. For a start, they have not been able to compensate for their low-level problems with word reading and word writing. The disadvantages here remain large ($d = 2$). In addition, these problems have effects on (or are accompanied with) a number of related deficits. The two most prominent are a general slowing of processing (reading, retrieval of information, arithmetic, writing, …) and less working memory resources available, arguably as a result of the low-level problems. The effect sizes of the associated problems are smaller ($.4 < d < 1$), but still visible. The first practical implication is that HE students with dyslexia are at a disadvantage when they have to read and write texts without technical support. Given that the effect size of the word reading and writing disadvantages do not seem to have softened relative to the primary school, there is little point in trying to address them any further. A better approach might be to help the students cope with them, by using technical help, such as text-to-speech software, spelling checkers, and calculators. This is particularly effective if syllabi are available in digital format (rather than on paper only). Other ways in which the students can be supported are by having the questions read out to them and by allowing them to answer orally. Such help is likely to be of much more benefit than trying (once again) to address the weakness of reading and writing individual words.

A second practical implication is that HE students with dyslexia are slower than controls. This means that they will be a particular disadvantage for tests and exams under time pressure (and without technical support). Lecturers really should ask themselves whether time pressure is an essential component of the skills and knowledge they want to test. If not, they are causing students with dyslexia an unfair disadvantage. On the basis of the review above, there are good reasons to argue that HE students with dyslexia should be given extra time relative to other students. Students with dyslexia themselves report being more relaxed and as a result being able to concentrate better due to an extended time limit during an exam. As such, granting them more time to finish an exam is justified. Students who are not dyslexic usually do not benefit from this measure. In their case granting them more time is unlikely to result in higher scores. An even better approach is to set up exams in such a way, that all students (also the disadvantaged) are able to finish within the foreseen time limit. This makes individual adjustment redundant. If students with dyslexia are not given enough time, they are not able to prove their full potential. A third practical implication is that it is meaningful for HE students with dyslexia to take some extra training in skills that are important in higher education. One of these skills is composing written reports and essays. Our research has shown that text planning is slightly compromised in students with dyslexia (arguably as a result of the extra resources needed for the low-level processing). So, it is worthwhile to take training on this aspect. Because HE students with dyslexia need more time to study, it is also important for them to have extra good time management. Again, this is something that can be taught to some extent. One of the advices of Steenbeek-Planting and Kleijnen (2011), is to systematically read aloud (and record) once each text one has to study, possibly in the presence of a friend or relative who can correct mistakes. This is something that can be done in the academic year, long before the exams start. It is extra work, but it is likely to be fruitful, because it practices the new vocabulary that must be mastered, and spaced learning helps to remember the contents.

Another way to reduce processing load, is making the slides used in classes available well before the class starts. During classes, students get a lot of information. The lecturer talks while slides are presented, and in the meantime students must take notes. When the slides are made available before class, students with dyslexia (and other struggling students) can already prepare for the class by reading through the slides. As such, the slow reading pace does not obstruct them in following the class and taking notes.

The above section provides clear theoretical and empirical evidence for the justification of compensatory means these students are entitled to compensate for their disability. Of course, using these compensatory means alone will not make a student with dyslexia pass but it does positively affect study success. Compensatory means should in no sense be reduced to a standard package. An individual approach seems crucial. What works for one student does not necessarily work for the next. An extensive assessment protocol, including the above cognitive skills will provide a personalized pattern of strengths and weaknesses and give the student a clear view on his abilities. This will also give tutor the necessary information to suggest effective compensatory means.

Raising awareness

In addition to the above suggestions about compensatory measures, students with dyslexia should be made aware of the challenges they will face in HE. The profile coming out of the studies shows challenges in a wide range of skills. It is important for students to know about the limitations they will be confronted with, so that they can prepare themselves and insist on having the arrangements outlined above. A better knowledge of their limitations may also help them not to overestimate their abilities. We cannot deny that the average performance of the dyslexics on nearly all described skills tended to be lower than that of their peers. Students with reading disability should know about these differences, so that they can organize their studies. For instance, many institutes of higher education nowadays provide their students with ways to spread the burden (e.g., by studying part-time or distributing the exams over extra sessions). It may be an idea to discuss these options with students (and their parents), certainly when their test performances are below average, so that they can prepare themselves better in the light of the specific difficulties they will be confronted with.

A final reflection on the guidance and support given to this subgroup of students is that we should be alert not to train helplessness but resilience. Dyslexia poses extra challenges (which society should acknowledge!), but they can be overcome by a mix of justified compensatory measures (such as extra time and technical support) and extra effort on the part of the student. Helping students to cope with these challenges is the best help we can give them for the rest of their career.

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Bibliographical Note

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Dr. Marc Brysbaert is Professor of Psychology in the Department of Experimental Psychology, Ghent University, Belgium. A grant from the Government of Flanders allowed him to set up a large-scale study of dyslexia in higher education, together with Maaike Callens and Wim Tops.

The study showed that the pattern of weaknesses and strengths in Dutch-reading students is very similar to the pattern present in English-reading students, suggesting that the profile is language-independent (at least for languages using an alphabetic script).