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Comment les capacités attentionnelles et les habiletés en motricité fine entre la maternelle et la première année influencent les habiletés en écritures ultérieures au primaire

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Attention and Fine Motor Skills at the First Grade Transition and Subsequent Writing Skills in Later Childhood

The *Rapport du Comité d'experts sur l'apprentissage de l'écriture* suggests that Quebec children and adolescents are showing increasing difficulty with spelling, punctuation, and syntax (MELS, 2008). Internationally, writing problems are extremely prevalent in primary school, peaking in fourth grade (NCES, 2003). Academic performance tends to stabilize by fourth grade (Alexander & Entwisle, 1998). These observations must be treated with a developmental perspective and are rooted in school entry characteristics.

General and Specific Objectives and Pertinence

The overall objective was to review and integrate the social science and medical databases to address how early attention and fine motor skills (around school entry) influence grammar, composition, and spelling skills in middle and later childhood. Although the literature suggests a cognitive shift toward integrated reading and writing systems between the early and later primary grades (Altemeier et al., 2006), they leave several unanswered questions in relation to current thoughts about: (1) The co-occurrence of early fine motor and attention skills and problems from preschool onward; (2) How early fine motor and attention skills relate to later gender differences in student writing (Savage et al., 2007); (3) The most critical period in the consolidation of writing skills; (4) Possible explanations about the enormous variation in mastery across at-risk student populations; (5) How students with ADHD often have motor difficulties which influence writing skills; and (6) How early intervention aimed at boosting fine motor and attention skills could ultimately change the course of student skill trajectories in writing. This literature review capitalizes on both the developmental neuropsychological and pedagogical perspectives to address these objectives. We aim to provide teachers and school personnel an accessible, organized, and up to date document which summarizes information on two understudied and neglected problems – attention and fine motor problems in kindergarten – influence subsequent writing in primary school. In terms of pertinence, this literature review aims to provide practitioners with information on early childhood intervention strategies that promote later writing skills and corresponds to Priority 2.1 which aims to examine the impact of individual factors on subsequent writing skills and the needs/actions expressed in the MELS *Plan d'action pour ameliorer du francais* (better preparing teachers, reinforce supportive measures; revisit priorities in French language teaching).

Methodology. We searched, reviewed, and integrated the educational, psychological, psychiatric, pediatric, and neuroscientific literatures for enlightening details on direct and indirect relationships between early attention and motor skills on later writing skills between kindergarten and sixth grade (ages 5 to 12) and high school (13 onward). We used the ERIC, Psychinfo, and medline search engines. Spanning two decades of research until 2012), we present a comprehensive, exhaustive, multidisciplinary account of the state of current thought on the specific objectives outlined in the prior section. Our aim was to cover journal outlets of both empirical and practical (clinical) impact. We also attempted to include articles on the relationship between attention and motor skills and subsequent writing skills in high school. Although there is some information in child development research found in Psychinfo and ERIC databases, this information is typically found in speech and language therapy and occupational therapy disciplines (e.g., orthophonie and ergothérapie) and developmental neuroscience under MEDLINE. Our keywords were attention; motor; inhibitory control in combination with writing, spelling, punctuation, and composition skills. Although a large number of articles and books emerged on the topic of ADHD, we only retained articles that directly to writing skills and attention or motor skills or both. When multiple publications from the same author group overlap in results, we only report on the most pertinent publication.

Introduction

It has been established that brain growth occurs at an exponential rate from birth to school entry (Shonkhoff & Philips, 2000). During early childhood, children learn to talk and listen as they learn to roll over, sit, walk, and then finally run. At school entry, which typically occurs around age 5, children need to arrive prepared to learn to read, do math, and write. Children spend 31 to 60% of their school days performing fine motor tasks and 885% of this is devoted to paper and pencil tasks that require writing (McHale & Cermak, 1992). As with literacy and numeracy, some children show difficulty with either the body mechanics of writing or with written production, or both. By the middle of primary school, most children have moved from learning to write to writing to express their thoughts and show evidence of their learning or note-taking. Nevertheless, 23% of fourth graders write proficiently at or above grade level and less than two-thirds write at a basic level, with 16% meeting requirements below the basic level (National Center for Education Statistics, 2003). Moreover, curricular demands for more complex writing tasks increase with advancing grades. As such, during the transition years from primary school to high school, children evidence a much higher prevalence of text generation difficulties, ranging from 6 to 22%, depending on region, gender, and first language status (Hooper, 1993). A developmental perspective on this prevalence suggests they are likely rooted in school entry characteristics.

Attention and motor skills are often overlooked as key skills on the first day of school. This report explores their importance in relation to later achievement in writing skills, which represent an essential competency for success in basic schooling. Our education systems need to maximize the potential of every birth because that child will eventually be eligible to enter the labor market. One way to do this is to improve a child's chances of meeting basic educational qualifications. The process leading to high school dropout by age 20 can be judiciously traced to kindergarten (Pagani et al., 2008; Vitaro et al., 2005). In fact, child characteristics in kindergarten predict successful transitions in the early grades (Pagani et al., 2001), which significantly forecast academic attainment by age 22 (Entwisle et al., 2005). For these reasons, how early characteristics forecast later academic performance is highly relevant (Alexander & Entwisle, 1998; Heckman, 2006).

School Readiness

School readiness is concerned with how prepared a child is for school. Ensuring that all children are ready to learn at school entry remains an international preoccupation considering the eventual socio-economic and health implications (Heckman, 2006; High, and the Committee on Early Childhood Adoption, and Dependent Care and Council on School Health, 2008). Recently, a prospective associational study across six international data sets sought to establish an empirically-driven definition of what kindergarten factors matter most for long-term achievement (Duncan et al., 2007). The consolidated results are remarkable for several reasons. First, cognitive skills (math and receptive vocabulary) showed the most power in predicting later math and reading. Second, and perhaps most importantly, early attention skills earned third place as a distinct predictor of later achievement (above and beyond the contribution of cognitive skills). Finally and unexpectedly, kindergarten behavioral adjustment and social skills showed no significant influence on later achievement in reading or math. This was the case across SES and even among children with relatively high levels of socio-emotional problems.

More recent replications of the Duncan et al. (2007) school readiness model have included fine and gross motor skills. Cameron et al. (2012) found that fine motor skills at kindergarten entry, in particular, strong design copy performance, tend to be associated with gains in literacy-related domains such as letter-word identification, passage comprehension, and phonetic awareness. The power of copying shapes even predicted the amount of improvement in these literacy-related domains by the end of kindergarten. Much like cognitive and attention skills, these ultimately predict later writing skills (Savage et al., 2007). In a large birth cohort of French-speaking children from the province of Quebec, fine motor skills made a significant unique contribution to the prediction of second grade math and reading above and beyond the original key elements (cognitive and attention skills) of school readiness (Pagani et al., 2010). Grissmer et al. (2010) replicated the same importance of fine motor skills for predicting third and fifth grade math and reading performance with British and American population-based longitudinal data of children.

Studies on school readiness must expand their outcomes toward writing achievement, given that the production of language skills are as important as math and reading achievement for later success (Altemeier et al., 2008). The neuroscience literature describes links between motor skills and achievement outcomes related to writing, especially around the critical developmental period around the first grade transition. To practitioners in the classroom, this is welcome news, especially given that both attention and motor skills are both amenable to early intervention (Belfield et al., 2005; Diamond et al., 2007; Lillard, 2005). Clearly, teachers need a more practical definition of school readiness (beyond reading and math readiness). Preschool classrooms must also focus on its most recent key early elements – attention and fine motor skills - and later writing skills. Teachers also need an elaborate model of school readiness that includes preparedness for the production of written material. The information in education databases do not typically include the wealth of information generated in the neuroscience, speech and language, and occupational therapy literatures. Thus, integration of disciplines is warranted to address the questions in this review.

Theoretical Underpinnings of attentional, motor, and writing processes

The executive system is a conceptualization of how the brain controls and manages other cognitive and emotional processes prefrontal areas of the frontal lobe. More specifically, the executive functions (EFs) are responsible for mental governance of the brain and exclusively apply to regulating goal-directed (and not automatic) behavior (Barkley, 2012). Said simply, EFs facilitate efficient, automatic processing of information necessary for thought and emotion. Goal-directed behavior such as learning, social interaction, managing emotions, and problem solving are clearly not automatisms. Nevertheless, EFs do facilitate the development of efficient, automatic processing of information, especially in light of increasing experience and skill (Denckla & Cutting, 1999). A goal can involve the management of emotion such as coping behavior or a problem such as learning. Consequently, EFs are important for knowledge acquisition and reflective problem solving because they require conscious efforts to inhibit automatic (reflexive or impulsive), irrelevant or over-learned response options. Goal-directed thought processes thus require planning, implementing, and maintaining/discontinuing/ adapting thought processing strategies, as needed (Zelazo et al., 1997).

There are three underlying EFs that enable people to control (self-regulate) and engage in goal-directed behavior (Lyon & Krasnegor, 1996): (1) inhibition; (2) mental set shifting; and (3) updating/monitoring. These are empirically validated governing (executive) components (functions) process information and action across time and space (Hughes, 1998; Miyake et al., 2000). Although the three main governing components are intercorrelated, they remain distinct processes with objectives of their own and feedback loops among each other during multitasking (Miyake et al., 2000).

Inhibition represents the primary function that supports the development of two other EFs: shifting and updating and monitoring (Carlson & Moses, 2001). A critical period of rapid brain growth in frontal and prefrontal brain regions, both recruited for inhibitory control, occurs between 36 and 48 months (Marsh et al., 2008). This maturation hones the ability to suppress (often less effortful) impulsive competing responses in the service of higher, more demanding goals (Kochanska et al., 2000). Although comparatively less dramatic, brain maturation continues to develop throughout middle childhood (Marsh et al., 2008). Inhibition, as a primary function, continues to develop through adolescence in light of ongoing mylenation processes.

Brain growth results in an orchestra of cognitive control skills, which are more developed offshoots of the basic functions: inhibition, shifting (also known as mental set shifting of linguistic information), updating working memory; self-monitoring, setting goals, and making plans. Reflective problem solving requires inhibition of automatic responses in order to plan, implement, or evaluate strategies in favor of a long-term goal. Inhibition delays an automatic or overlearned response in order to engage in goal-directed behavior and block interference (Barkley, 2003). The act of inhibiting more influential or powerful responses allows a delay in which a person can plan and/or implement self-directed or self-regulatory actions. Inhibition can occur either as a behavior (response control) and/or as a thought process (attentional inertia). Although some conceptualizations of cognitive control may emphasize one over the other in terms of importance, the fact of the matter is that cognitive inhibition predicts behavioral inhibition and vice-versa.

Because inhibitory control plays such supportive role as a primary function, the other two self-regulatory functions trail behind behavioral inhibition in development. Thus, inhibition developmentally precedes and coordinates its two underlying EFs: (1) shifting, which requires transferring attention between objects and objectives (Blair, Zelazo, & Greenberg, 2005; Hughes, 1998; Miyake et al., 2000) and (2) updating/monitoring, which includes self-monitoring, updating working memory, setting goals, planning, and revising (Barkley, 2003; Miyakeet al., 2000). One could safely conclude that inhibition is an essential ingredient for these two other functions Diamond, Carlson, & Beck, 2005). That is, it is necessary but not sufficient on its own. Its true potential is achieved with the two other complementary functions.

EFs represent the cognitive control processes that monitor recursive planning, translating, and revising in the problem-solving process used to produce a written objective (Zimmerman & Risemberg, 1997). Much like with other cognitive and behavioral processes, EFs predict overall written output, note-taking, and report writing in normally developing populations (Altemeier et al., 2006; Hooper et al., 2002). Interestingly, the Hayes (2000) process model is very compatible with the sequential EFs framework put forth by Zelazo et al. (1997): problem, plan, execution, evaluation.

Like a well put together orchestra, the EFs drive learning activities and motor skills (Cameron et al., 2012). The functions of the executive system control the integration of visual and linguistic information and help the retrieval of linguistic information from memory while learning to read, write, and do arithmetic (Barkley, 2012). For example, in both reading and writing, efficient retrieval of the phonological codes for letters and letter units, for example, may be affected by the ability to suppress irrelevant codes and quickly search and retrieve the relevant response. The same processes apply to letter copying in preschool, which represents the most important fine motor skill for later achievement. During the writing process, EFs control the processes that guide thinking, emotion, and behaviors used to achieve a written product. Specifically, writing can be viewed as recursive problem-solving and EFs monitor planning, translating, and reviewing/revising processes. EFs provide the basis for two influential models that explain the cognitive sequential processes in writing (Hayes and Flower, 1980; Zelazo et al., 1997) whereby the writing process is driven by problem representation, followed by plan generation and then execution (intending/rule use), and evaluation (error detection/correction).

Developmental Issues

1. *Writing and its development.* Developmental theories of writing skills have generated two streams of information: Writing processes and products. Process theories have sought to explain development in terms of the strategies or "processes" that the writer uses to create those products. There is consensus that process involves planning, translating, and revising. The most comprehensive of models is the cognitive problem-solving paradigm (Hayes, 2000). Although this model is directly relevant to thought processes that generate writing, it lacks an explicitly developmental dimension. Attempts at elaborating upon developmental processes are mostly based on cross-sectional work.

The product perspective, which represents the outcome of the writing process, mostly focuses on the nature and size of the written production (Berninger et al., 1996). The emphasis on concrete outcomes has resulted in a more developmentally-oriented research. The precursors to writing are known as fundamental graphic art, which occurs at approx 18 months. Toddlers discover the graphic traces left by scribbling with a crayon or pencil (Puranik et al., 2012). From that critical period onward, the typical developmental trajectories of writing skills follow a predictable evolution: from random scribbling; zig-zag lines; picture drawing; letter-like figures; variation in elements without segmentation in to units; linear word-like arrangements of elements; true letters; words; sequences of related words; to sentences. At about 36 months, children’s graphic productions which represent written expression can be differentiated from actual depictions of events (pictures). From kindergarten entry to the end of first grade, the development as children's writing progresses from producing pictures without text and replicating letters, single words, a series of words (clauses), to eventual sentence-length productions (Traweek & Berninger, 1997). Children develop written language skills by first producing single words, combined word units, incomplete clauses, and eventual sentences just as they develop oral language skills by progressing from one word at a time, combining multiple word utterances, to eventual complete sentence utterances.

2. Attention Development. The human brain triples in size from birth to age 2, followed by critical periods in preschool development of cognitive control, language, number, motor, and social skills. Such growth occurs in direct response to transactions with other people and objects in the environment. Maturational milestones in response to brain growth are characterized by critical periods in the development of attention skills. Newborn eyes can wander 8 to 12 inches and recognize familiar voices. By 3 months, infants can: follow a moving object with eyes; react to "peek-a-boo"; smile when smiled at; and turn head toward sights and sounds. By 6 months, infant can smile at self in a mirror and imitate familiar actions. By 12 months, infants can: study objects by shaking, banging, throwing, dropping) imitate gestures; respond to music; accomplish simple goals (see and then crawl to toy); Find hidden objects easily; and recognize names. By 18 months, toddler can: identify an object in pictures; laugh at silly actions; look for objects that are out of sight; follow one direction; solve problems by trial and error; recognize self in the mirror/pictures; look at person who is talking. By age 2, toddlers can: take things apart; explore surroundings, point to 5-6 parts of a doll; ask for information; listen to short rhymes; laugh at joke; point to eyes, ears, or nose. By age 3, child can: pay attention for about 3 minutes; match objects; follow one-step commands; and repeat simple rhymes. Between ages 4 and 5, child can: copy patterns and shapes; draw a body; and tell stories.

By kindergarten, the principle components of attention skills are listening attentively, not being easily distractible, being able to concentrate, and task focus. Kindergarten attention represents a constellation of skills which underlie inhibitory control and account for their own variance in cognitive skills, apart from general intelligence (Blair, 2002; Blair & Razza, 2007). Such skills are pivotal in modulating reactivity, including approach, avoidance, and inhibition, and effortful control of behavior in response to cognitive, emotional, and social situational demands on self-regulation (Chang & Burns, 2005; Dennis & Brotman, 2003).

Attention skills, as early as preschool, provide the foundation of goal-directed self-control behavior (which are managed by the executive system in the brain) and are a prominent correlate and precursor to math and literacy skills in kindergarten (Blair & Razza, 2007; Mischel et al., 1989). Several longitudinal studies beginning in preschool suggest that early attention problems are prospectively associated with reading underachievement and disability (McGee et al., 1991) use of special education services (MacDonald & Achenbach, 1999), and psychosocial maladjustment in high school (Mischel et al., 1989). Problems with attention in nationally representative samples of typically developing American and Canadian school age children have shown large negative effects on educational attainment and achievement (Currie & Stabile, 2006). In fact, even low levels of such problems predict reduced achievement outcomes and suggest more important risks than physical health problems on educational attainment and achievement. We have replicated these results with Quebec-born, French-speaking children and finding that early attention predicts later writing skills (Pagani and Fitzpatrick, forthcoming). Finally, rather compelling evidence points to long-term impact of attention skills on scholastic performance, social competence, and even coping with stress and frustration (Shoda, Mischel, & Peake, 1990). Such skills seem crucial for staying on a low-risk behavioral course toward successful high school completion (Pagani et al., 2008; Vitaro, Brendgen, Larose, & Tremblay, 2005). We will revisit the attention component when discussing theoretical issues.

3. *Fine Motor Development.* The rapid brain growth from birth to 24 months is followed by critical periods in motor development. Developmental milestones from birth to one month include opening and shutting hand, bringing hand to mouth, swiping and dangling objects, and grasping and shaking hand toys. From age four to seven months, there are emerging perceptive abilities (like vision, touch, and hearing) in combination with increasing fine motor skills (like grasping, rolling over, sitting up, and possibly even crawling) which foster sensorimotor zones on fingers. From eight to twelve months of age, increased gross motor mobility skills such as crawling, creeping, crouching, standing and taking steps promote further promixal-distal development of fine motor skills. By 18 months of age children begin to scribble and turn pages in a book, and put socks and mittens

on by themselves. By age two they can build block towers, pour liquids into containers, drink from a straw, and feed themselves with a spoon. Three-year-olds typically scribble spontaneously, hold a crayon well, fold paper, and drink from a glass in with one hand without aid. By age 4, they try to use a fork, can hold a pencil, scribble name, can draw (movements driven by arm and not hand) a circle or a face, cut paper with scissors, can unbutton and buckle clothes but cannot button or buckle yet, and feed self with little spilling. By kindergarten, key fine motor skills include but are not limited to proficiency at holding a pen, crayons, or a brush and the ability to manipulate objects like scissors and opening a carton of milk (Pagani et al., 2010). Fine motor skills, is the most predictive motor skill of later achievement (Pagani et al., 2010). Specifically, copying from a visual stimulus (letter- or shape-copying for example) is the most effective activity (Cameron et al., 2012).The power of design copy suggests that much like speaking and reading, writing is a cognitive task that simultaneously requires fine motor skills, EF coordination, and hand–eye coordination (Grissmer et al., 2010).

Relation Between Early Attention and Fine Motor Skills and Later Grammar and Spelling Skills

1. The co-occurrence of early fine motor and attention skills and problems from preschool onward.

(a) Skills. Attention and fine motor skills recruit common sensory systems and cortical structures in the brain (Diamond, 2000; Marsh et al., 2008). Brain development occurs through a sequence of major events, beginning with the formation of the neural tube gestation and intense myelination during the first two years of life. Anatomical development typically in sensorimotor areas first, subsequently expanding progressively into dorsal and parietal, superior temporal, and dorsolateral prefrontal cortices. Thus, cognitive, fine motor, and attention milestones are interdependent, recruiting each other toward higher-order cognitive functions, mostly driven by the frontal cortices, especially during Piaget's sensorimotor period (Marsh et al., 2008).

Although they make independent contributions to achievement and skill development (Cameron et al., 2012), there are several reasons to believe that motor skills and attention (specifically the EF function of inhibitory control) collaboratively matter in school readiness and academic achievement (Diamond, 2000); the first four of which are suggested by Diamond (2000).The first is mental governance; All EFs play a key role in learning both cognitive and motor skills. That is, without self-regulated and goal-directed behavior, we would not have coordinated and meaningful skills in either area. This is why deficits in either attention or motor skills result in longer learning time and thus fewer academic experiences. The second is mutual recruitment; Neuroimaging studies consistently suggest mutual recruitment between the prefrontal cortex (where inhibitory control functioning is processed) and the cerebellum (where motor skills are processed). Specifically, tasks which require both attention and motor skills to work in tandem require collaboration between the prefrontal cortex and the cerebellum, and this is beneficial for overall development. During preschool and early elementary school years, most learning endeavors in the classroom involve both motor and cognitive processes (e.g., counting with fingers and using other gestures to do arithmetic, acting out parts of stories, describing letter shapes with hands, cutting and pasting letters, and hand clapping to learn syllables). The third is interdependence between brain regions; Injury to either the prefrontal cortex or cerebellum results in a reduction of neural activity in the collaborative parts of the other counterpart. The fourth is common dependence of one brain region; The shared use of the basal ganglia in both cognitive and motor tasks that require sequential and coordinated categorization over a time (as in choreographed movements in martial arts which require the orchestration of both inhibitory control and complex motor skills). The fifth is comorbidity; Children with diagnosed with attention-related or learning disorders often experience motor impairments and vice-versa. The brain has positive plasticity to compensate for regions that are either inactive or dysfunctional, which accounts for cases of resilience where individuals with one deficit may show compensatory strength in the other skills. Finally, the sixth is resource dependence; tasks that require complex motor control tend to cognitive resources more than do tasks with simpler motor requirements (Berger, 2010; Seger, 2006). School-age children who evidence automaticity in coordinating their motor skills may have greater processing capacity available to learn more complex concepts, including symbolic representation of letters and numbers (Berger, 2010; Seger, 2006).

Similarly, writing and reading are also integrated skills that developmentally intercede with each other because they involve common sensory systems and cortical structures in the brain (Bezrukikh & Kreshchenko, 2004). Students first learn to read and write as separate language systems, and then, with the help of some form of mental self-government, they learn to integrate the two systems by fourth grade (Altemeier et al., 2006). Listening, speaking, and reading skills developmentally predate writing skills; much like the inhibitory control processes that govern children’s attention become more complex self-regulatory problem-solving functions

(Wakely et al., 2006). That is, attention skills (inhibitory control mechanisms) make their own unique contributions to reading and writing as individual systems in the earlier grades; however, as students progress toward a more demanding curriculum in the later grades, they require more complex self-regulation skills in order to fully achieve the integration processes across the two systems (Altemeier et al., 2006). Pedagogical approaches adapt themselves to facilitate this transition from the basic to the more complex curriculum (Fitzgerald & Shanahan, 2000).

(b) Problems. Early difficulties in writing and reading are likely rooted in shared sensorimotor precursors of speech and comprehension skills, including but not being limited to processes involved in the grammatical structure of speech and word formation, logical-grammatical constructions, and connected speech (Bezrukikh & Kreshchenko, 2004; Molfese et al., 2006). The most important characteristic that forecasts later writing is phonetic knowledge which is predicted by both early attention and fine motor skills (Cameron et al., 2012; Savage et al., 2007). Both fine motor and attention problems play an important cortical role in the development of basic physical writing difficulties such as dysgraphia (Adi-Japha et al., 2007). In an investigation of underlying writing and reading difficulties, Bezrukikh & Kreshchenko (2004) found that basic motor and executive function (memory and attention) skills play a significant role as school readiness skills in the first grade transition, they gradually diminished in importance by third grade when more self-governing executive function skills (voluntary organization and working capacity, and perseverance skills) become increasingly important from fourth grade onward.

Brainwise, writing processes are driven by a well orchestrated relay process between the frontal lobe (which drives EFs) and the parietal lobe (which drives action-oriented abstraction and motricity). The left superior parietal region has been proposed as a writing center in the brain where memory codes for letters and numbers may be generated and stored for production (Richards et al., 2009a; 2009b; 2009c). Thus, it is no coincidence that children with attention problems often have writing problems, depending on whether only right superior parietal or both right and left superior parietal regions differ from normal.

Executive system dysfunction is at the root of dyslexia because affected individuals have difficulty with organization, automatization, and integration of multiple processes and perform poorly on EFs of inhibition and shifting/cognitive flexibility. Children with dyslexia are slower in their processing time and make more errors because they experience more mental interference (dysfunction in inhibition). EFs are correlated with writing tasks in normally developing populations and influence handwriting and overall written output, and contribute to performance on integrated reading–writing tasks (note-taking and summarizing). The most critical of developmental periods occurs during grades 3 and 4, when EFs seem to matter most for written expression. This is when the predictive ability of children's EFs seems to be at its maximum, thus forecasting their academic life course (Altemeier et al., 2008).

Even handwriting automaticity requires executive control for the integration of multiple processes, including motor planning, orthography, orthographic-motor integration (via the orthographic loop of working memory), and processing speed. Consequently, EFs contribute to explaining dysgraphia (handwriting and/or spelling disability) via impairment involving inhibition, attention shifting, and updating/monitoring working memory (Swanson, 2000). These upset the organized and interactive multitasking that must occur to produce written material. Becker (2006) tells us that multitasking places extensive demands on working memory capacity and concludes that the time expended in the writing process is as important as working memory load. Metacognitive processes require long-term memory as well.

2. How early fine motor and attention skills relate to later gender differences in student writing. Although there are no differences in gross motor scores, on average, girls have higher fine motor scores than boys in infancy and in the preschool years (Darrah et al., 2008). Boys are also more at risk of executive function problems (working memory and inhibitory control, which ultimately affects the other functions (Barkley, 2012; Berlin & Bohlin, 2002; Carlson & Moses, 2001). Such impairments explain more attention problems and disorders in boys than girls (Barkely, 2012).

A problem with any one function in the executive system places later writing skills at risk. Although boys tend to do better with oral fluency tasks, they tend to underperform compared to girls on written fluency tasks (Berninger & Fuller, 1992). This is probably because the EFs are thought to control the memory search processes underlying writing fluency. Moreover, there is a 3:1 male-to-female prevalence ratio of ADHD which is thought to be primarily explained by EF deficits (Barkley, 2012). ADHD tends to co-occur with motor deficits (Pagani et al., 2012). This is because performing a motor skill is not a random automatic bodily activity. Rather, it requires concentration, planning, and execution skills (all of which rely on the executive system and its functions). Tying one's shoes, cutting paper, or holding pencil requires many EFs at the same time. Therefore, gender differences in EFs favour girls and composing text, whether for a dictation or a story requires multitasking in the main functions of the brain's executive system.

In kindergarten, phonological awareness is strongly related to both attention and motor skills (Cameron et al., 2012). Savage et al. (2007) explored the unique predictive validity of phonological awareness and early literacy measures, and other pupil background measures taken at age 5 in the prediction of writing performance at age 11. Phonological awareness was a significant unique predictor of writing, reading, maths, and science performance (tests and teacher assessments), even after early literacy skill and letter-knowledge was controlled. Girls outperformed boys in writing performance, as measured by individual tests and teacher reports.

Indeed, conclusions about gender differences in dyslexia and in EFs are challenged by the genetics literature which suggests that the underperformance of boys is actually due to the greater risk of maturational delay in boys in frontal lobe development, thus predicting inferior performance on tasks requiring a well synchronized orchestra of EFs, like writing. In the end, it seems to come down to impaired inhibition, which ultimately upsets the other functions (Altemeier et al., 2006). Thus, because the brain's executive system governs both attention and motor activity, impaired EFs in boys are most likely to explain many observed reading and writing problems, especially if they meet diagnostic criteria for a developmental reading and/or writing disability.

3. A critical period in the consolidation of writing skills. There is a critical period in the development of the distinct EFs between 36 and 60 months (Zelazo et al., 1997), which lays the foundation for learning in kindergarten and early schooling. In written literacy, the most critical of developmental period occurs during grades 3 and 4, when the consolidation of attention, motor, and cognitive skills seem to matter most for composition, spelling, and punctuation (Altemeier et al., 2008). That is, the predictive ability of children's EFs seems to increase at that developmental point, forecasting their life course achievement in writing skills. Internationally, this corresponds to the peak prevalence in writing problems (NCES, 2003).

4. Possible explanations about the enormous variation in mastery across at-risk student populations

There are large individual variations in executive function and dysfunction which regulate or dysregulate the writing process, respectively. Poor writing is most often predated by inhibition problems which drive both supervisory attention and working memory (Barkley, 2012). Individual differences in EFs may affect both the low-level and high-level level writing processes alike (Berninger & Amtman, 2003). Nevertheless, the order is developmental: lower level processes predict performance in higher level processes. In younger children of preschool age, lower level writing processes include automatic letter writing of the alphabet from memory, all of which require functions such as inhibition, shifting (also known as mental set shifting of linguistic information), updating working memory; self-monitoring, setting goals, and making plans (Richards et al., 2009a; 2009b; 2009c). Both handwriting and spelling require executive control and the integration of multiple functions as processes, including motor planning, orthography, orthographic motor integration via the orthographic loop of working memory, and processing speed (Rosenfield & Berninger, 2009). A deficit in lower level functions will undermine handwriting and/or spelling (Rosenfield & Berninger, 2009). A deficit in lower-level writing processes will undermine higher level composition processes (Berninger & Amtman, 2003). Individuals with dyslexia are mostly impaired by executive dysfunctions in inhibition, switching set, and updating verbal working memory (Berninger et al., 2006b).

5. How students with ADHD often have motor difficulties which influence writing skills. Both attention and motor skills contribute to later writing skills. In extreme conditions, like attention disorders, we observe significant motor difficulties in discrete motor processes (gross, fine, and perception-motor skills) which impair meaningful activity in everyday life. Fine motor deficits, especially those involving manual dexterity (using scissors, tying shoes, hooking up a zipper and manipulating buttons on clothing) and visual motor integration (needed for design copying of letters) are most remarkable in this group (Brossard-Racine et al., 2011), which represents from 3 to 12% of the population of elementary school students. These fine motor deficits significantly predict less legibility and slower speed of writing in medically untreated children. We must recall that ADHD represents the most important executive function disorder of childhood (approximately 5% of the school population). Those attention problems but do not meet the 6 diagnostic criteria for ADHD represent

between 25 and 27% of the classroom population (Barkely, 2012). The link between attention and motor skills and later writing achievement merits extensive discussion in light of this review.

First, copying letters, which is a precursor to writing and phonetic knowledge, requires good working memory and good visual motor integration (Cameron et al., 2012). Children with attention disorders and attention problems (which do not meet the criteria of disorders) tend to have poor inhibitory control, which makes it difficult to disregard information around them that is unimportant to the task at hand. In other words, inhibitory control, as an executive function, requires working memory and attention to help the student focus on a learning task or a classroom situation. Kindergarten attention skills can improve, and when they do, they predict better task-orientation, persistence, and cooperative behavior in the classroom through to grade 6 (Pagani et al., 2012). If they do not improve during kindergarten, poor attention skills translate into poor classroom engagement throughout elementary school. Early design copy not only predicts later writing skills but many other long-term skills that are important to overall achievement (Cameron et al., 2012; Grissmer et al., 2010).

Second, children with classroom attention problems and movement disorders (i.e., inhibitory control deficits) tend to show poor visual motor skills (Sortor & Kulp, 2003)., especially eye-tracking ability (Feifel et al., 2004; O'Driscoll et al., 2005), which are considered a fine motor skill. This is an excellent example of how EFs come before or determine motor skills. Eye tracking is defined by an individual's eye movement and eye-fixation patterns in the visual pursuit of an object (a word, letter, number, equation) and is determined by eye muscle control. It taps into tap into motor planning and temporal processing (Joiner and Shelhamer, 2006; O'Driscoll et al., 2005). Eye-tracking is an essential fine motor skill for design copying (e.g., letters and numbers and shapes) and early reading and early arithmetic skills. As typically-developing children age, their eye movements become more accurate and controlled (Rayner, 1998). Eye-tracking predicts success in long-term academic pursuits (Deans et al., 2010). Children and adults with ADHD may also have unique patterns of eye movement, particularly in regard to visual tracking tasks that require response inhibition of automatic eye movements, with no gender or age differences. They have longer reaction times and have greater difficulty maintaining fixations on objects they process visually (e.g., letters, numbers, shapes, equations). This leads to significantly more eye-tracking errors, which are related to academic difficulty (Chambers et al., 2006). Because higher-order oculomotor functions are managed by the inhibitory control function of the executive system, there are improvements in eye-tracking in response to methylphenidate treatment (Allman et al., 2012).

Both of the above characteristics can impair early writing in terms of legibility and production speed, which is a motor skill that gradually becomes a perceptual-motor cognitive skill, around the end of third grade. The consolidation of early motor and attention skills facilitates the transition toward perceptual-motor cognitive skill, which are necessary for higher-order writing skills. Poor consolidation due to poor inhibition can lead to difficulties in punctuation, spelling, and composition. Reading can also be undermined because of the inability to curb interference (James & Gauthier, 2009). Long-term math achievement seems also undermined by poor consolidation of these difficulties (Pagani et al., 2010).

6. How early intervention aimed at boosting fine motor and attention skills might change the course of student skill trajectories in writing. There is a movement toward providing cognitive control training for all typically developing children rather than just those who reach a clinical cut-off for ADHD or learning disabilities. These are conceptually rooted in the understanding that the brain comprises a governing system, the executive function, which controls and regulates cognitive and emotional processes. This is a huge leap in educational interventions, as it brings the brain back into discussions regarding classroom behaviors. The target age range for cognitive control interventions is large, being between 3 and 12 years of age. There is scientific support for a number of approaches that seek to train self-control; that is, improve the EFs (see Diamond & Lee, 2011 for more information). These are: (1) Computerized working memory training such as CogMed program (Bergman Nutley et al., 2011; Klingberg et al., 2005), especially for 8 to 12 year olds; (2) Reasoning and/or speed training with a combination of computerized and noncomputerized games (Mackey et al., 2011); (3) Aerobic exercise to improve prefrontal cortex functioning (Hillman et al., 2008); (4) Martial Arts Training, which is most effective with 8 to 12 year olds (Lakes & Hoyt, 2004); (5) Mindfulness training through meditation, self awareness, yoga, and sensory awareness activities (Flook et al., 2010) or biofeedback training (Gruzelier et al., 2006); (6) Classroom-based interventions such as Tools of the Mind (Diamond et al., 2007).) and Montessori programs, which are especially effective for preschoolers (Lillard & Else-Quest, 2005); and

finally (7) Ecological adjuncts to child-focused programming for caregivers such as parents and teachers to build their own cognitive and emotional control in order to teach it to their children and students, respectively (Bierman et al., 2008; Verreault et al., 2011; Webster-Stratton et al., 2011). In their review of these most effective interventions, Diamond and Lee (2011) conclude that: Children most in need for the training benefit the most; More specific training influences very specific outcomes; The most effective programs are those that demand many EFs at the same time and keep children continually challenged, especially when the programs adopt a global approach as in martial arts or classroom-based interventions; No expensive equipment is needed; and lastly, the most effective approaches are those that add mindfulness or a character development component. A recent print-referencing intervention has tried to combine mindfulness, knowledge about forms and functions of print, and motor skills related to emergent writing. McGinty et al. (2011) has found success in boosting both print knowledge and phonological awareness with preschool children. This is an example of multi-focused classroom interventions that can be administered universally.

To ensure quality, we will briefly cover programs that have only conducted randomized clinical trials. In a doctoral thesis, Amui (2006) obtained very positive results by training object control skills (striking, bouncing, catching, kicking, throwing, and rolling a ball) with preschoolers, compared to control group children`s usual routine (playing outside). Prevention of preschool motor difficulties can be successfully implemented during infancy (Spittle et al., 2010). Goodway et al. (2003) tested 35 minutes twice per week for nine weeks of motor skill instruction in 5-year-olds at risk of developmental delays. They found significant positive effects in object control and locomotion skills. There are distinct cultural approaches to motor skills interventions to consider as well. With 5-year-olds, Venetsanou and Gambas (2004) experimented with a weekly 45 minute traditional Greek dance program for twenty weeks and found significant effects on general motor proficiency at a twenty week follow-up. In Taiwan, Wang (2004) tested a 30 minute, twice weekly creative movement program weekly for six weeks and found significant improvements in gross motor skills. In their systematic review, Reithmuller et al. (2009) concluded that 90% of published studies and 71% of unpublished studies (that met their criteria for review) were effective in improving motor development. These are group-based and average about 11 sessions.

Only 20% involved parents, which represents a considerable limit in transferability and reinforcement of the skills learned in the treatment component.

Kindergarten teachers need to know that the development writing depends on confluent motor, attention, and memory skills. The most important recent finding is the discovery that letter writing at preschool age forecasts orthographic development in the child (Puranik & Apel, 2010, represented in Appendix A). Puranik et al. (2010) have consistently found that children's ability to write the letters of the alphabet significantly predicts spelling skills during dictation, oral spelling, and tile spelling. Once they are able to physically write the majority of the alphabet (19 of 26), children's writing skills are considered ready for a promising first grade transition. In fact, one of the most powerful precursors of writing development is being able to produce one's own name at kindergarten entry (Puranik & Lonigan, 2012). The assessment of motor and attention skills is accessible and straightforward to assess in the classroom. Similarly, teachers are in an excellent position to assess and strengthen children's name-writing and letter writing skills at school entry. Parents play a crucial role as an adjunct to any preschool intervention. In one study, after being taught scaffolding strategies and overcoming obstacles in play, parents were encouraged playing games with their children (ages 4 and 5) at home for at least 30 to 45 minutes per day for five to eight weeks, while children received sessions at preschool. Games were designed to enhance inhibitory control, working memory, attention, and visuospatial, planning, and motor skills. Results showed improved attention regulation and motor coordination (Halperin et al., 2012).

Conclusions from the Literature

Internationally, writing problems tend to peak in fourth grade, with one American study showing that only 23% of fourth graders met grade specific proficiency requirements (NCES, 2003). Writing consumes a large percentage of learning time in the classroom. In this review, we provided detail about how early childhood fine motor and attention skills, in addition to cognitive skills, come together as essential components to future writing. Differences in early risk generate gender differences in the precursors of student writing. Nevertheless, individual differences in the pace of child growth and development remain important when trying to pinpoint a precise critical period for any given student. Because ADHD is primarily an executive function disorder in the brain, students with ADHD often show motor difficulties which subsequently influence the pace, legibility, and learning cadence in spelling, punctuation, and composition. There are a number of universal early interventions aimed at boosting fine motor and attention skills that could ultimately change the course of student skill trajectories in writing. There is scientific support for a number of approaches that seek to train objective focus and self-control. The most effective programs are those that demand the simultaneous orchestration of EFs and keep children continually challenged and mindful of their objective, especially when the programs adopt a global approach as in martial arts or classroom-based interventions.

Interventions that aim to improve motor skills often involve training object control and locomotion skills (striking, bouncing, catching, kicking, throwing, and rolling a ball) with preschoolers, as these purposefully improve eye-hand coordination and attention. Most of the universal interventions were planned to diminish child impulsivity, which makes them quite appropriate and often tested on children with ADHD. Medication (methylphenidate) improves executive function skills, which in turn, improve both attention and motor skills (planned movement and eye-tracking). Educational and parenting supports are necessary adjuncts. Several specific teacher strategies during preschool emerged as important. First, we cannot understate the value of enrichment time invested in design copy skills and teaching children to write letters to the point of successful dictation. Both skills use many EFs at the same time, and are crucially important for later writing skills. It must be understood that poor reproduction of letters, shapes, and numbers are not just the result of compromised fine motor and attention skills. Rather, working memory and eye-tracking seem problematic for some children. For these children, finger pointing may be important as an adjunct motor skill in both reading and letter-copying. In Evans et al. (2008), having an adult reader point to the text while reading enhanced 4-year-olds memory for print elements. This suggests that pointing to the text may be an effective strategy for increasing the amount of attention children will invest in print during writing and reading tasks. Pointing may facilitate preliminary mental representations about the shape/spelling of printed words. In fact, teachers may need to inform children and parents that the need for finger pointing to maintain eye-tracking during literacy activities may last throughout one’s academic career.

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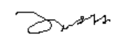
Appendice A. Le développement de l'orthographe chez l'enfant.

Score	**Étape**	**Consigne**	**Jus**	**Lit**
0		Pas de réponse		
1	Graphique	Un gribouillage produit par des traits de crayons		
2		Une forme simple bien formé (ex : un carré, un semblable de cercle ou de triangle) pas produit par de simples traits, mais en contrôle		
3	Alphabétisé	**Un symbole conventionnel** : l'écriture contient au moins une vraie lettre qui n'est pas reliée au mot phonétiquement. Un point ou un cercle ne sont pas considérés comme des symboles conventionnels.	M,P	B,T,S
4		**Enchaînement aléatoire de lettres** : plus qu'une lettre au hasard (non liées phonétiquement)	Fes, lap, re	Tol, Ver
5	Phonétique précoce	**Représentation phonétique précoce** : l'écriture contient au moins une lettre qui est phonétiquement liée au mot demandé à l'enfant à n'importe quel endroit.	Sus, uls, ouj	Lre, ies,ris
6		**Première lettre du mot correct** : première lettre du mot correctement écrit et au bon endroit avec/ou d'autres lettres phonétiquement liées	J, Jur,Jes	Les, Lot,lir
7	Phonétique	**Plusieurs représentations phonétiques** : l'écriture contient 2 ou 3 phonèmes liés au mot, mais avec des lettres qui se répètent. La première lettre du mot doit être correcte.	Jusu, Jssu	Liti, Ltti
8		**Orthographe inventé** : l'écriture contient plus de deux lettres qui représentent la plupart des phonèmes du mot avec toute tentative de représenter une voyelle.	Juss, Jous	Leit, Litt
9	Correct	**Orthographe conventionnel** : le mot demandé à l'enfant est écrit dans sa forme conventionnelle.	Jus	Lit

Modifié à partir de Tangel & Blachman (1992).