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USING TABLET TECHNOLOGY IN PRESCHOOL AND EARLY KINDERGARTEN FOR THE IDENTIFICATION OF CHILDREN AT RISK FOR READING DIFFICULTIES

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Introduction

In 2016, approximately 3.8 million children in the United States entered public school kindergartens (NCES, 2016) joining the estimated 656 million children of primary–school age worldwide (United Nations Department of Economic and Social Affairs, 2017), where they embarked on a journey of learning to read and write, skills that will carry them through high school and beyond. For up to 20% of these children across different languages and countries, this journey carries with it a risk of school failure due to an inability to learn to read as expected (Brunswick et al., 2010; Elliott & Grigorenko, 2014; Görker et al., 2017; Shaywitz et al., 1990; Ziegler & Goswami, 2005). Intervention research demonstrates that targeted, evidence-based programs in kindergarten and first grade can substantially improve reading outcomes for those children who require intensive intervention in order to become successful readers (e.g. Catts et al., 2015; Fricke et al., 2013; Hatcher et al., 1994; Hatcher et al., 2004; Torgesen, 2000; Vellutino et al., 2004). However, pre- and beginning readers are not routinely screened for risk in part due to the formidable logistical and financial challenges of providing millions of children with a full clinical assessment of the language and cognitive skills that are precursors to reading. One solution to the impracticality of administering a full diagnostic assessment to every child is a rapid screener that would identify children with an elevated risk of reading failure. Such a screener would provide a systematic and reliable basis for close monitoring and evidence-based instruction within a general education setting. Further, a screener that pointed to resources, teacher-training opportunities and evidence-based instructional strategies could aid parents, daycare providers and teachers to address weaknesses in the component skills of reading before or without formal diagnosis. In the following sections, we first describe the research on reading demonstrating that early screening is not only feasible but also necessary in order to prevent reading failure. Next, we outline the critical components of a high-quality screening tool for early reading risk and describe the

unique supports and considerations that digital technologies, and in particular tablet apps, bring to bear on screening young children. We share our app development process as one example of the ways in which mobile technology can serve as a tool for the assessment of risk. Finally, we highlight potential clinical and educational implications of early screening.

Typical reading development

For individuals with typical reading development, reading may be an effortless and automatic activity. However, underlying skilled reading is a multifaceted network of competencies for both understanding language meaning and recognizing printed words (Rumelhart, 1994; Scarborough, 2001; Vellutino et al., 2007). General language competencies include knowledge of word meanings, facts and concepts, as well as mastery of grammar and the structure of language at the sentence, text and discourse levels (Flax et al., 2009; Hemphill & Tivnan, 2008; Scarborough, 2001). Word recognition requires skill with phonology, the sounds of a language, and orthography, the written symbols associated with those sounds (Stanovich & West, 1989). In addition, the automatic recognition of familiar sight words is essential to fluent and rapid reading, particularly in languages such as English in which there are frequent exceptions to regular 'rules' for spelling and sound correspondence (Cunningham & Stanovich, 1997). Thus, children must learn both to understand a spoken system of language and also to decipher printed words corresponding to that oral language by recognizing patterns in sound and visual symbols in order to become successful readers.

Predictive indicators of general language and printed word–reading competencies can be found even before children have begun to read: *vocabulary knowledge* and *oral sentence comprehension measure* early oral language skills upon which later reading comprehension and reading fluency depend (Catts et al., 2016; Hulme et al., 2015). *Phonological awareness* and *phonological memory* are indicators of pre–readers ability to perceive, remember and manipulate the sounds that distinguish words, and *rapid automatized naming* and *letter-sound* knowledge demonstrate pre–readers ability to integrate oral and visual symbols in language. Remarkably although these constructs do not directly involve reading words or text, in preschool and kindergarten these six constructs are good predictors of later reading success and failure (Catts et al., 2015; Gilger et al., 1996; Lyytinen et al., 2015; Pennington & Lefly, 2001; Scarborough, 1989; Snowling et al., 2003; Snowling & Melby–Lervåg, 2016; Torgesen, 2000).

Atypical reading development

Although individuals typically display a broad spectrum of ability in both reading and its precursor skills (Snowling et al., 2003), in this article we address the lower end of the spectrum, termed in the clinical literature 'specific learning disability in reading' or 'developmental dyslexia'. We understand this condition from a developmental perspective as an atypical, neurocognitive variation (Gilger & Kaplan, 2001), and one that bears profound consequences for children's educational success in a modern learning environment that heavily relies upon fluent, rapid reading. When individuals with such variation, which we call 'reading difficulties' in this article, do not receive appropriate intervention, the consequences can be devastating: children who do not learn to read in elementary school risk not only academic failure but also the social and psychological consequences of this failure that include poor self-esteem, anxiety and negative life outcomes (McArthur et al., 2016; Mugnaini et al., 2009; Quinn et al., 2001). These negative outcomes may be preventable as early differences in the component skills that are foundational for reading can be detected in preschool and kindergarten. Early detection of reading risk is

especially important as the earlier intervention occurs in a child's schooling, the more successful the intervention is likely to be (Hatcher et al., 1994; Wanzek et al., 2013).

Early timing of intervention is further supported by neurobiology research indicating that the development of networks of brain regions commonly associated with language and the integrative processing required in skilled reading is influenced by modifiable factors such as practice with language and literacy in addition to environmental factors such as socioeconomic status (e.g. years of parental education), and also genetics (Logan et al., 2013; Norton et al., 2015; Ozernov-Palchik et al., 2016; Taylor et al., 2010). Variations in reading abilities are associated with neurobiological differences that emerge early in brain development, particularly in left-hemispheric areas and networks related to reading (Ozernov-Palchik et al., 2016). Brain differences in these reading-related regions are already evident in infants (Leppänen et al., 2010; Langer et al., 2017) and pre-reading children (Raschle et al., 2012) who have a family history of reading difficulty suggesting that atypical brain characteristics may predate reading failure and can be targeted even before children learn to read.

Although evidence from neurobiology, intervention research and clinical psychology supports the efficacy of early identification and intervention before children have begun to fail, in the U.S. children are often referred to clinical evaluation only after several years of failing to learn to read as expected, and the process of determining need for intervention is a lengthy one, often taking many months. In many schools, children do not receive intensive intervention until the third grade or later, when they have failed to learn to read and are also well past the optimal window for intervention (Ozernov-Palchik & Gaab, 2016). This late timing of intervention has limited efficacy: children who start out as below-average readers in first grade, on average, continue to show below-average performance in fourth grade (Juel, 1988) and on into high school (Landerl & Wimmer, 2008; Shaywitz, 1999).

Early identification and screening

As research demonstrates, early identification and instructional support can provide a viable alternative to reading failure (Hatcher et al., 1994; Torgesen, 2000; Wanzek et al., 2013). Based on the research discussed in the previous paragraph examining predictors of reading outcomes, we propose that an early screener for reading difficulties in preschool and early kindergarten should evaluate seven indicators: phonological awareness, phonological memory, rapid naming, letter-sound knowledge, vocabulary, oral comprehension and familial risk for reading difficulty. With such a screener, we might support individual needs and risk profiles within the home, community or general education context. In this way, early difficulties with language or other foundational skills that are crucial for skilled reading may be remediated through intensive and evidence-based responses to screening such that later clinical diagnoses are tempered or not required.

The idea that early support for reading development is efficacious and desirable is certainly not new: the importance of pre-reading literacy skills and kindergarten and pre-literacy intervention strategies that address those skills has also long been recognized in educational research and practice (Lonigan et al., 2011; Snow et al., 1998) and has resulted in numerous early literacy assessment tools. A large proportion of these rely upon word reading with the result that their predictive power depends upon previous exposure to decoding instruction. While fluent word reading in and after first grade does predict later reading outcomes, word-reading tasks are unable to distinguish children at risk for reading failure without prior instruction. Thus for the purpose of pre-reader screening, we discuss in the next section only those early literacy assessments that do not rely on word reading. These measures can be divided into three general categories: composite batteries, curriculum-based formative assessments, and rapid screeners.

Overview of existing early literacy screeners

Perhaps the most effective and widely available current screening batteries for pre-readers are composites of diagnostic standardized assessments that include all key component areas of phonological awareness, phonological memory, rapid automatized naming, letter (sound) knowledge, vocabulary and oral language comprehension. These largely non-digital assessments are conducted one-on-one by a professional with a child using visual stimuli in paper presentation books and/or recorded audio stimuli played on a recorder or MP3 player. While currently no single commercial battery encompasses all component areas, clinical or school evaluators and testing companies are able to compose 'packages' of assessments that are tailored for the screening of young children and generally include tasks that have been validated and nationally normed with young children. Children's performance is scaled on a normative distribution with the lowest quantiles as markers of risk (although many measures were normed on relatively small and non-representative samples). Composite batteries have high reliability and validity as well as predictive value demonstrated in scientifically validated research and are ideal for clinical diagnosis. However as screeners, composite batteries are extensive and often time-consuming, requiring anywhere from one to three hours to complete. Clinical batteries of standardized assessments require trained staff to administer tasks to children on a one-to-one basis, score children's responses, and interpret the results for a lay audience. Most standardized assessments are costly and sold under requirement of extensive clinical or academic training at the graduate level, a staffing resource not available to most schools and clinics for screening all pre-readers. Thus, although composite batteries are effective and comprehensive diagnostic tools, they are not a feasible method of widely screening pre-readers for reading risk.

Pre-readers may also be screened through curriculum-based, formative early literacy assessments evaluating the child's progress in a sequence of curricular program objectives, levels or benchmarks. Often employed as program screeners, these formative assessments are less expensive and time-consuming than composite batteries, requiring from only four to sixty minutes to administer. Although many curriculum-based assessments are only available in paper-and-pencil format, others are digital and may even incorporate game-like elements such as animated characters, goals and rewards to motivate completion when measuring multiple, independent component skills. Intended for use on a large-scale, potentially with all children in a classroom or entering a school, these tests are often more user-friendly than standardized batteries and may require little to no training to administer while providing automated scoring and interpretive reports. In addition, tools published by universities or education districts may have been reported in peer-reviewed forums and have passed through psychometric validation studies. However, formative assessments generally focus on proximal skills salient in the classroom environment, are oriented towards next steps for instruction in specific curricular programs and are criterion- rather than norm-referenced. Often not constructed to provide a normative testing distribution, they may lack sensitivity or specificity to accurately identify individual children who fall in a critically low quantile of the population as a whole (Catts et al., 2009; Jenkins et al., 2007; Johnson et al., 2009).

The third and rapidly growing category of reading screening tools comprises rapid screeners, defined as brief curriculum-independent assessments whose goal is a fast but sensitive and specific, categorical classification of children as at-risk or not for later reading failure (Johnson et al., 2009). Several screeners, though of uncertain efficacy, exist in questionnaire format. Most validated pre-reading screeners directly test one or more of the component skills of reading: those that assess multiple reading components have higher sensitivity and specificity than those that target a single skill (Jenkins et al., 2007; Ozernov-Palchik et al., 2017). There is currently not one screener that directly tests all seven optimally predictive components outlined earlier,

and phonological awareness and/or letter-sound knowledge are the most common sub-skills evaluated. Many screeners are paper-based, though digital tests are increasingly available from private commercial entities or public initiatives by states and institutes of higher education. While some commercial screeners are costly, others, often online screeners are easily accessible, available at low-cost, and generally do not require extensive training to administer while providing automated scoring and score interpretation. Furthermore, digital technology has enabled some of these tools to incorporate creativity and imagination in engaging children through game-like tasks. For example, the need to evaluate multiple disparate component skills is well-served both by the content gamification of a meaningful story line and animated characters and also by structural gamification features such as a journey or quest, badges, points and levelled play (Deterding et al., 2011). However, the principal drawback of many commercial rapid online screeners is their lack of psychometric evaluation: only eight of the over fifty rapid pre-reader screeners we examined for the purpose of this paper have published peer-reviewed validation studies, all emerging from state or public institution screening initiatives. While rapid digital screeners hold great promise for the future of reading risk screening, it is critical that these tests be constructed in a valid and scientifically supported manner, provide a normative score indicating risk, and encompass the pre-reading skills that have been demonstrated to predict later reading success (Glover & Albers, 2007). As there is no single screener that meets all of these criteria, at present a comprehensive reading screening initiative must employ several disparate tools for a comprehensive assessment of reading risk.

Developing a tablet screener

One way in which an optimal screening tool can be constructed to be resourceful, comprehensive and developmentally appropriate is through the incorporation of mobile digital technologies. Tablets and mobile apps incorporate features that are uniquely suited to the developmental capabilities of the young child: in 2013, an average of 72% of U.S. preschoolers engaged with mobile technology on a daily basis (Rideout et al., 2013). Touch technology accommodates young children's still-developing fine motor capacities by allowing simple gestures to convey complex intentions (Rust et al., 2014). Individualized feedback provides cognitive scaffolding through hints or cues and also affective scaffolding through verbal encouragement and other forms of extrinsic reward (Yelland & Masters, 2007). Advances in hardware technology allow devices to be constructed at a comfortable handling weight and size for young children (Petersen, 2015). While research is still inconclusive regarding best practices for integrating technology into children's learning in developmentally beneficial ways (Spektor-Levy et al., 2017), as the chapters by Sylva and Roberts and by Lee in this volume discuss, tablets and mobile apps are a highly accessible technology for young children facilitating not only entertainment, but also social interaction and educational content.

Beyond interaction and instruction, mobile technology is rapidly becoming an integral tool in clinical assessment. Digital formats allow item presentation to be highly standardized and precisely timed (Hadwin et al., 2005; Singleton, 2001). Internet server connectivity as well as local data storage in mobile devices permit both data retention and transfer avoiding data loss and enabling collection and sorting of large datasets for psychometric analysis and the creation of baseline norms (Santos–Febles et al., 2015). Secure cloud-based web services provide the capability to store and aggregate large-scale data compliant with health privacy laws facilitating updates of norms, stimuli and software. Mobile clinical testing apps can be especially useful in contexts in which full assessment in a clinic or hospital is simply not possible, overcoming the limitations of geographically remote or resource-restricted environments. As we have described,

one such context in which clinical assessment is often sorely needed but infeasible using non-digital tools is that of preschool screening.

Consequently, we set out to construct a pre-reader screening tool that would be comprehensive and yet short, psychometrically valid yet not require extensive tester credentialing, and efficient yet engaging and developmentally appropriate while keeping in mind the advantages and challenges of composite batteries, formative assessments and digital screeners. We envisioned a screening app as a cost-effective, mobile platform that could be readily accessed in a variety of settings. Designed as a 30-minute interactive and engaging game, the app would screen for early indicators of atypical reading development. Free or low-cost, wide distribution would allow large data aggregation and a dynamic standardization process with norms updated on an ongoing basis and refined for validity with local populations. After screening, the supporting adult would receive a risk profile and a set of activities, downloadable curricula, illustrative videos, resource list and recommendations for next steps. These would be targeted specifically for educators, clinicians and parents as evidence-based strategies that would give all children the opportunity to reach their full reading potential (see earlier references).

Constructing a tablet-based risk screener ideally involves four phases: 1) task and stimulus design, 2) pilot testing and initial psychometric review, 3) validation and norming, and 4) development of evidence-based supports. We consider here the first design phase in which, based on prior research, we chose the five pre-reading components: phonological awareness, phonological memory, letter-sound knowledge, rapid naming and the family history of reading difficulty and the two language components, vocabulary and oral language comprehension that are most predictive of future reading abilities (see earlier discussion). For each of these components, we carefully examined the validated, standardized tasks used in composite batteries and peer-reviewed studies (e.g., Catts et al., 2005; Chiat & Polisenska, 2016; Norton & Wolf, 2012; Ozernov-Palchik et al., 2017; Pennington & Lefly, 2001; Scarborough, 1989).

For digital tools in particular, this first phase provides a crucial opportunity to consider the match (or mismatch) between ideal test design and technology implementation. We next provide three examples of the ways in which the benefits and constraints of the digital format are considered during design: in item selection, response modality, and motivation.

Design examples

First, while each subtest of a psychometrically validated composite battery may consist of tens of items requiring up to forty-five minutes administration time, a useful rapid screener must assess all seven features of reading risk in a relatively short period of time without the presence of a trained evaluator. While digital formative measures can use computer-adaptive testing techniques to rapidly shift to items that match a child's skill level, for a normative assessment the psychometric requirements of item response theory require a consistent item set to be administered (Hadwin et al., 2005). Thus, instead of providing the full formative range of evaluation, a normative risk screener in development must be brief by focusing on a limited but consistent item set discriminating children at-risk from those not at-risk. In our app, we therefore included only items that bordered the divide between at-risk and average skill levels eliminating very easy items that even at-risk children would be expected to get correct as well as very difficult items that only advanced children would be likely to master. Psychometric considerations thus did not allow us to avail of computer-adaptive capabilities while timing considerations required us to define a restricted and optimally discriminant item set.

The balance of digital capabilities with appropriate testing methodology is also reflected in choices regarding response modality that potentially impact the assessment's developmental

suitability for the child. For example, vocabulary can be evaluated receptively by speaking the name of an object, such as an orange, and having the child point to (or touch) a picture of the object, or expressively by displaying an orange and asking the child for its name or for an alternate name if the child provides a broad category, such as 'fruit' instead of 'orange'. In a mobile app environment without a trained test administrator, speech recognition software would be required to record, score, and potentially provide immediate feedback to a child's response in a productive task; this immediate feedback is not currently technically feasible. One drawback of receptive tasks, though, is that they are fundamentally multiple-choice activities. A child may pick a correct object simply by chance and the fewer choices presented, the higher the probability that the child receives a correct score. The common testing solution of providing many choices may be counterproductive as the visual and fine motor skills of preschoolers are still developing and may result in tapping errors when the correct response area is small (McKnight & Fitton, 2010). On the other hand, confirmatory gestures such as double-taps or object-dragging used for older children and adults may be difficult for young children (Dubé & McEwen, 2017; Vatavu et al., 2015).

Although computer-adaptive testing and speech recognition capabilities of the digital format might be unsuitable for shortening task length or for speech recognition of expressive vocabulary, in other cases digital technologies can facilitate resourceful screening, for example with rapid naming. Rapid automatized naming is an inherently expressive task: in the rapid object naming format, this task requires the child to name familiar objects in several rows of pictures as quickly as possible while the child's score is based upon the time required to complete all rows. Rapid automatized naming is the least commonly assessed component skill of reading in current digital screeners, perhaps in part due to the difficulty of capturing speech onset and offset times. However, rapid naming tasks are in fact good candidates for digital analysis because speech scoring is relatively simple: first, because there is a limited set of words the software must identify and second, because scores do not depend upon fine differences in pronunciation of the object names or computer feedback during the task. Although immediate scoring is not presently technologically feasible, voice recordings can be stored and transmitted online for later automated analysis and reporting. Whether or not the digital format supports a particular task or response modality therefore depends not simply upon the modality itself but also upon the task goal and response evaluation criteria.

In addition to item selection and response modality, user motivation provides a third example of balance between optimal test design and digital implementation. The engaging game play of many rapid digital screeners illustrates how an imaginative narrative in a gamified scene can keep children attentive to and engaged in tasks they often find boring or frustrating in traditional psychometric batteries (Brewer et al., 2013). Motivational principles such as novelty, e.g., in exploring a virtual world that can be interspersed with elements of surprise; reward, e.g., for completing tasks or staying engaged in the game; and social interaction and approval, e.g., from a virtual 'friend' (Dichev & Dicheva, 2017) engage children just as adults. For preschoolers, however, it is important to keep in mind potential developmental differences that impact their interaction with gamification elements. For example, in more demanding language-based tasks requiring inhibitory control, children do not begin to consistently demonstrate theory of mind, a construct that reflects a person's ability to understand another's point of view or imagine themselves in another's place, until around the age of three or four years old even though they may possess this capacity as toddlers (Scott & Baillargeon, 2017). Participating in gamified role-play thus requires metacognitive skills and information-processing capacities that may be challenging for preschoolers. In addition, young children may be more easily distracted than older children or adults from the primary assessment task by excessive visual detail, extraneous

sounds, or challenging physical interactions such as dragging and dropping (Brewer et al., 2013). Further, they may not be able to decipher an ambiguous or complex screen interface (Dubé & McEwen, 2017; Masood & Thigambaram, 2015). An optimal interface for young children is thus relatively simple, well-guided and sparse, while retaining the basic motivational elements of novelty, reward and social interaction.

As the examples of item selection, response modality and motivation demonstrate, the first design phase of a tablet-based screening tool requires a fine balance among what is techno-logically feasible, psychometrically valid and developmentally appropriate. Although we do not describe these in detail for the purposes of this chapter, there are three additional phases equally critical for constructing an effective screener. First, stimuli must be pilot-tested and test items must be reviewed for psychometric properties. Second, validation, norming and standardization studies must be conducted and submitted for peer-review of results. Third, practitioner tools and references must be constructed so that skills flagged as needing support can be accompanied by practical and evidence-based resources. Only after all four phases are complete is a screener ready for public dissemination.

Clinical and educational implications

Our knowledge about the neurobiological origins of atypical reading development and the effectiveness of early intervention was made possible by neuropsychological studies and con-firmed and refined in recent decades by brain imaging research. Complementary advances in child-friendly technologies such as tablets and mobile apps make the utilization of this knowl-edge for early universal reading risk screening feasible. Screening is crucial because early risk for reading difficulties is not deterministic: cognitive, perceptual, genetic and neurobiological factors interact with the home and educational environment to shape the child's developing brain and later reading ability (Peterson & Pennington, 2015). Providing schools, clinics and communities with a digital, cost-effective and efficient, scientifically validated tool for early risk identification can potentially impact positively upon the lives of thousands of children who would no longer be required to fail to learn to read in order to receive support to learn to read. We end with a caution, however, that an efficient screening tool will be of little use if children do not subsequently receive evidence-based supports through close monitoring, instruction and potentially, further diagnostic evaluation. In addition, the supports must target the specific read-ing components flagged in the screener (Glover & Albers, 2007), whether phonological aware-ness and memory, letter-sound knowledge, rapid naming, vocabulary or oral comprehension. If universal screening of pre-readers as well as evidence-based responses to screening for children found to have elevated risk are in place, early and customized remediation programs, ideally delivered through well-trained teachers within general education, may in the future be possible for all children. Such programs themselves may have a ripple-up effect in terms of resource sav-ings and academic improvement as remediation in the early grades is more efficient and effective than in later years and leads to improved academic, psychological and social development for children formerly at risk of reading and thus academic failure.

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