3rd Baltic Sea Conference on Reading
17th Nordic Reading Conference
Turku, Finland
August 14-16, 2016

The developing brain and digital technologies: Implications for reading

Kehittyvät aivot ja digitaalitekniikan: Implications for lukeminen

About 40,000 years ago Paleolithic women and men created pictures on the walls of caves. It was the dawn of the first era in technology. There have been many more eras in the course of history. Across countless generations and changes in technologies, the human brain has been influenced and changed by these technologies.

Socrates famously accused the scroll and tablet of ruining the ability of his students to think and remember. Today the use of the words ‘scroll’ and ‘tablet’ mean something entirely different, but what is not different from Socrates’ time is the search to understand how rapidly changing and expanding technology experiences, in the form of digital devices and media, might be influencing and perhaps changing the brains of children.

For today’s children digital experiences are the defining characteristic of their daily life. They have never known it any other way. These young children may spend up to 35 hours a week with digital devices and media. As a result digital experiences can be their single largest daily activity outside of sleep.

So many experiences that a new genre of research as begun entitled “extended cognition” (Wilmer et al., 2016)

The many hours of digital experiences have doctors concerned. For example, the American Academy of Pediatricians (AAP, 2015) has urged no screen media use for children under 2 years-of-age and “technology free zones” for older children. So AAP believes that something is happening to our children, and it might not be positive!

So, to the point of this discussion---what do these hours of digital experiences mean for children learning to read—and their teachers. To answer the question we must step back and review what we know about changes to the neurobiological circuitry that forms the basic building blocks of reading.

Simply put, children learning to read must build functional neurobiological circuitry that integrates oral language processes with print language processes. This takes time and environmental opportunity---as well as the development of basic biological processes like cell growth, neural pruning and myelination (Horowitz-Kraus, et al., 2015).

As a result of the integration, cerebral changes happen and there is direct evidence from studies with young children and adults of what, where and when this happens. While much is yet to be understood (Poldrack, et al., 2015), the neurobiology of reading is an active brain imaging research area. (e.g., MRI, EEG/MEG, diffusion weighted imagery). A comprehensive review appears in *Nature* (April, 2015; Dehaene, et al., also, *Current Opinion in Neurobiology,* 2013, Wandell, et al., 23, 261-268).

- f (q) MRI---Functional (f) magnetic resonance imaging—good at locating the circuitry of reading. Quantitative MRI (q) measures tissue properties of circuitry.
- EEG/MEG---electroencephalography magnetoencephalography---good at temporal measures of circuitry.
- Diffusion weighted imaging---good at measures of signal strength also circuitry

EEG devices are available in low-cost, headset-wireless, brain-computer interfaces (e.g., companies Emotiv; NeuroSky).

For example, direct imaging evidence implicates circuitry changes in:

- visual processing speed
- visual discrimination
- attention to visual stimulus
- phonological analysis
- semantic fluency
- inter-hemispheric interaction (especially between vision and language)

Of interest to inter-hemispheric interaction….a recent fMRI study with young adults reported in *Nature* (28 April, 2016, Huth, et al.) offered the first semantic atlas of the cerebral cortex indicating where the natural speech meanings of words are located (grouped by related categories). The study refutes the notion that word meanings are only left-lateralized.

So back to the question at hand, How might children's digital experiences or habits influence and possibly change the neural processes (i.e., biologically-driven neural circuitry) that influence learning to read.

In time we will have answers, for example the Generation R Study in the Netherlands and the ABCD Study in the US (NIH, 2016) should provide some answers. In the former, researchers are tracking 7,000 people from their birth to adulthood. The people, selected at birth for study, are now 10-13 years of age. Cognitive development, neural imaging and life-style are part of the study. In the latter, 10,000, 9-10 years are being tracked through adulthood.

What are the current hypotheses about the question of possible influence and/or change to neural processes from digital experiences?

CONTINUUM OF DIGITAL IMPORTANCE

Hypotheses

MINOR ------------------------------------MAJOR

A B/C D

On the **MINOR** end of continuum is the first hypothesis. Call it A. This hypothesis suggests that digital experiences influence brain development but no more so than any other experiences. For example digital devices and media may steal attention but they do not change attention processes. In short, cultural tools may change rapidly but biologically-based neural processes do not. Children from yesterday are the same as today (Schulmeister, 2015).

Moving toward the **MIDDLE** of the continuum are two other hypotheses.

The first in the **MIDDLE** (hypothesis, B) suggests that processes are not changed (hypothesis A) BUT the temporal development of the processes could be influenced and as a result could be accelerated or delayed (age expansion or compression).

The next one in the **MIDDLE** (hypothesis, C) suggests that digital experience could lead to change BUT this is not a permanent change.

On the **MAJOR** end of the continuum is hypothesis, D. Digital experiences are influencing and permanently changing neural processes. The result has been called the “new techno-brain”. Learning is not hardwired but plastic. Throughout evolutionary history, the brain has changed or been reshaped/recycled (language, writing, arithmetic). But beyond evolutionary history can the brain change in a short period of time?

Yes! Human, primate and non-primate studies have found that environmental experiences can change neural mechanisms. The two most commonly cited examples with children come from studies with deaf/hard hearing children as well as children (physically healthy at birth) who experienced early stress and abuse. In all studies there is direct evidence that environmental experience, in the form of sensory deprivation, permanently changed neural processes.

Of note, recent neuroscience research has found that some people may have genetic variations that leave their brain processes more susceptible to change from environmental experiences---such as digital. For example, recent research with autistic spectrum people have found genetic variations that could lead to just such susceptibility (Martin et al., 2014).

So, which brain processes might be influenced or changed?

1. Attention
2. Self-regulation
3. Working memory
4. Speed and efficiency of information processing
5. Visual and auditory processing
6. Semantic and syntactic cognition including inferential reasoning (abstract-concrete)

What would change look like?

Let’s use attention as an example. Neuroscientists have learned that each shift of attention takes time and this happens because each shift means that orienting and control centers across the brain must activate neurological circuits.

However, they have also learned that the brain is more efficient without the constant shifts of attention. Nevertheless, hours of digital experiences change that. Constant shifting of attention is the new norm for children because they are immersed in daily digital experiences—and the attention processes are influenced and changed accordingly (Loh & Kanai, 2015: Small et al., 2009).

Of note, before the advent of neuroimaging direct research with young children, there were behavioral research studies that suggested indirect evidence for change. The term ‘indirect research’ means that the behavioral studies did not focus on the brain processes but suggested what brain processes may have been changed (for example, television and game studies). Today, behavioral studies are still used but are combined with neural imaging.

Before beginning, a couple of cautionary notes.

A first note, all neural processes require environmental experiences for their development and are constrained by biologically-based neural circuitry development. Two emerging literacies (listening-speaking) are ‘hardwired’ into these neural circuitries through evolution and only await environmental experiences for development. Two other emerging literacies (reading-writing) are culturally-based and depend upon co-opted neural circuitries and environmental experiences for development (Deaene, et al, 2015).

A second note, neuroimaging research has documented mutually supportive and intertwined relationships between neural processes across the entire brain. For example, working memory tasks are supported by attention, self-regulation, and information processing mechanisms. So, changes to one by digital experiences can influence and perhaps change other processes.

A third note, all digital experiences are not the same and all children’s responses to the digital experiences are not the same across regions of the brain. In fact just a few weeks ago researchers revealed that 97 new regions of the brain had been discovered to go along with the 83 that were known (*Nature*, July 2016, Van Essen et al.,) So, given these cautionary notes---let’s take a look at what <u>might</u> be happening in the brains of our young children.

Attention

‘Attention network’ theory divides the process into three components—alerting, orienting, and control. Simply put, the alerting component establishes and maintains readiness to react. The orienting component selectively focuses attention. The control component maintains attention. While each component appears to have discrete neural circuitry, they function cooperatively.

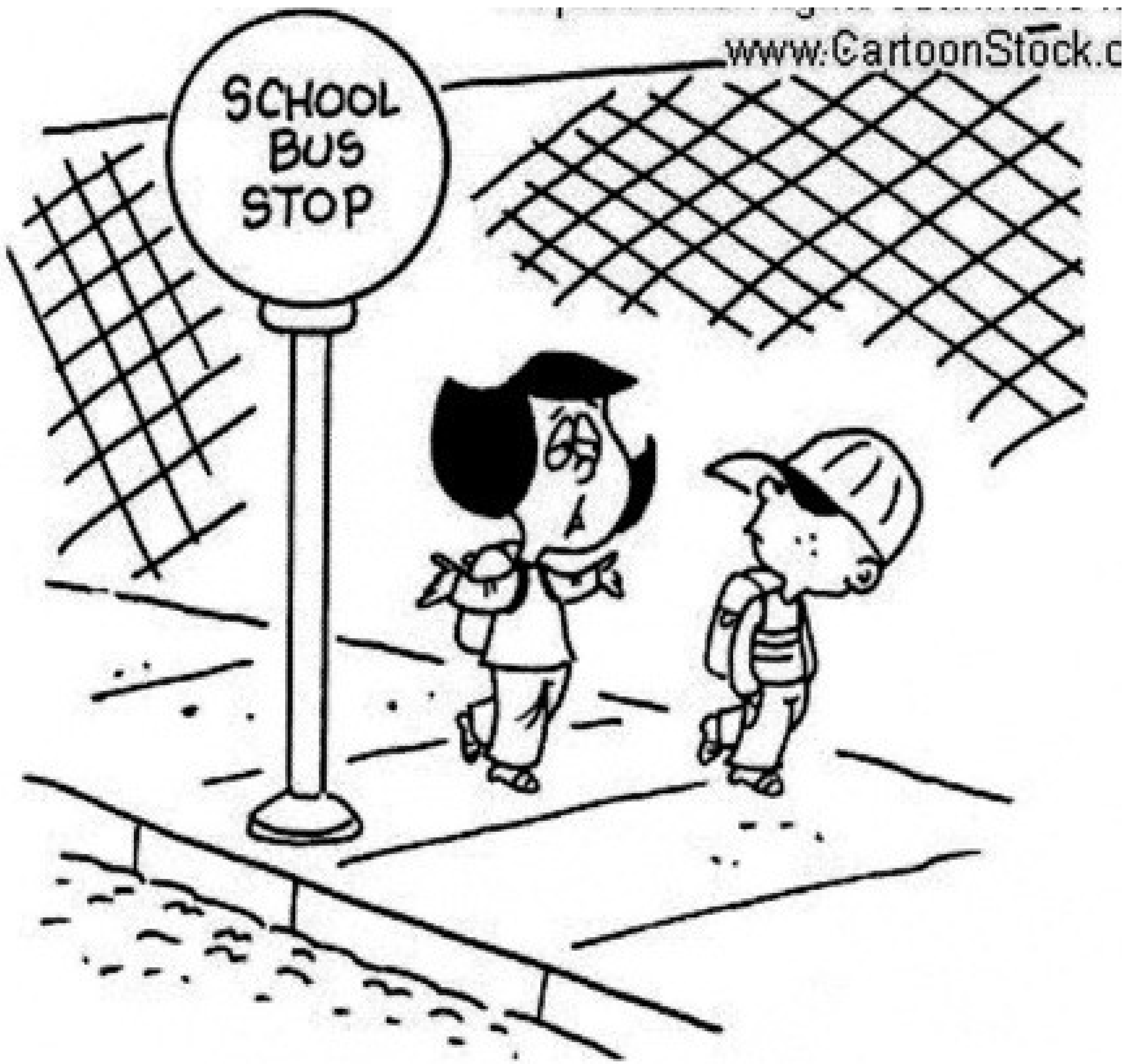
The orienting response and control components have been found to be particularly susceptible to the influence of media use in television viewing studies. What appears to happen in television viewing is the ‘repeated refocusing of attention’ caused by constantly changing content. Which suggests that as children learn to attend to rapidly changing content they block out background distractions while concurrently reorienting and controlling attention.

Neuroscientists have direct evidence that each shift takes time and this happens because each shift means that control centers in the frontal lobes must activate neural circuits. However the brain is more efficient without the constant shifts. As a result neuroscientists have suggested that the constant shifting of attention needed in today's digital world could lead to a tolerance or habituation to a state of constant re-orientating. The outcome is a change to the attention components and a state of continuous partial attention (Small & Vorgan, 2009).

Some researchers have suggested that the effects of digital experiences on brain processes, like those suggested in the continuous partial attention view, account for the growing number of children diagnosed with ADHD…and the apparent sense that today's children have shallower and shorter attention spans with high levels of distraction and reduced self-regulation---including reduced impulse and gratification control (Wilmer et al., 2016) .

In addition, possible changes in attention could result in shallow information processing, reduced contemplation (deep thinking), more rapid non-linear attention shifts perhaps driven by novelty and stimulation, decreased retention of information, more skimming and scanning, and reduction in long term memory replaced by transactional memory (Loh & Kanai, 2015). (transactional—memory about where to locate information not the information)

Self-regulation



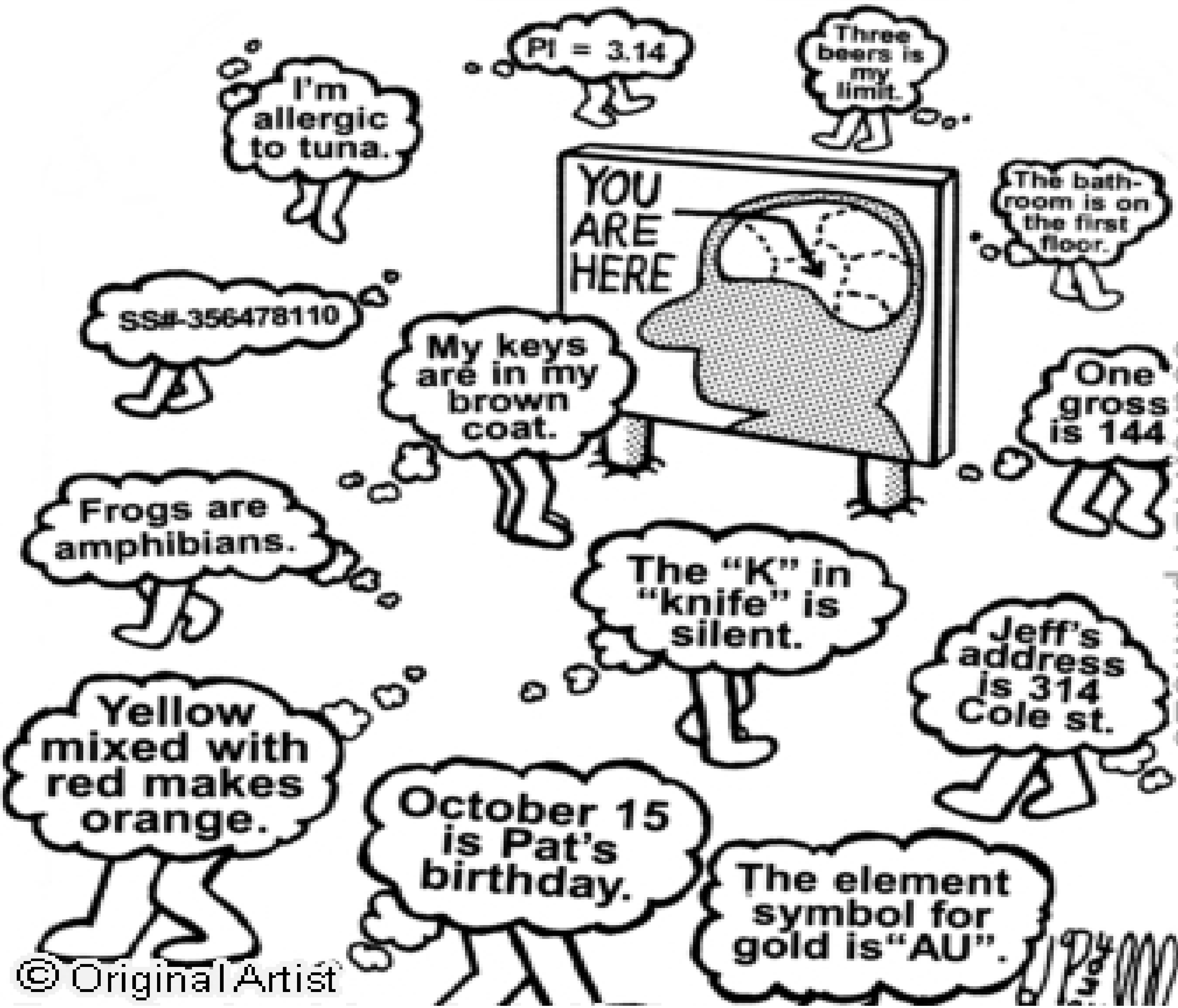
" BUT IF YOU DON'T LEARN TO READ AND WRITE, HOW ARE YOU EVER GOING TO TEXT?"

Self-regulation involves the ability to engage, sustain, modulate or change mental functions to achieve a goal or complete a task (meta-cognition). For example in a word recognition task children must attend to the relevant visual and auditory features of the word, hold information about those features in working memory, inhibiting distraction while retrieving relevant vocabulary level semantic and syntactic information from long term memory. Quite a task for a young child!

There are lots of opportunities for digital experiences to influence self-regulation in both positive and negative ways. A positive view would suggest that the hours of daily digital experiences will provide more opportunities to learn how to adjust and assign resources to tasks--multitask. A negative view would suggest that if children cannot adjust and assign resources the brain’s self-regulation mechanism maybe hijacked. There is evidence this can happen!

The Hijacking----In television viewing research, involving ‘Sponge Bob Square Pants,’ UK researchers found that preschool children---watching the fast paced program—experienced immediate negative effects on self-regulation. These negative effects have <u>not</u> been previously reported in a slower paced programs like Sesame Street (Lillard & Peterson, 2011).

Working Memory


I'm allergic to tuna.
PI = 3.14
Three beers is my limit.
YOU ARE HERE
The bath-room is on the first floor.
SS#-356478110
My keys are in my brown coat.
One gross is 144
Frogs are amphibians.
The "K" in "knife" is silent.
Jeff's address is 314 Cole st.
Yellow mixed with red makes orange.
October 15 is Pat's birthday.
The element symbol for gold is"AU".

Working memory is a complex mechanism that enables the processing, updating and maintenance of information as well as associative links with information in long term memories. It is fundamental to all core cognitive processes including those responsible for emerging literacies and beginning reading. There are visual and auditory working memories: Each has been implicated in the development of emerging literacies and beginning reading—and each can be deployed to varying degrees depending upon task needs (Dirk, et al., 2016).

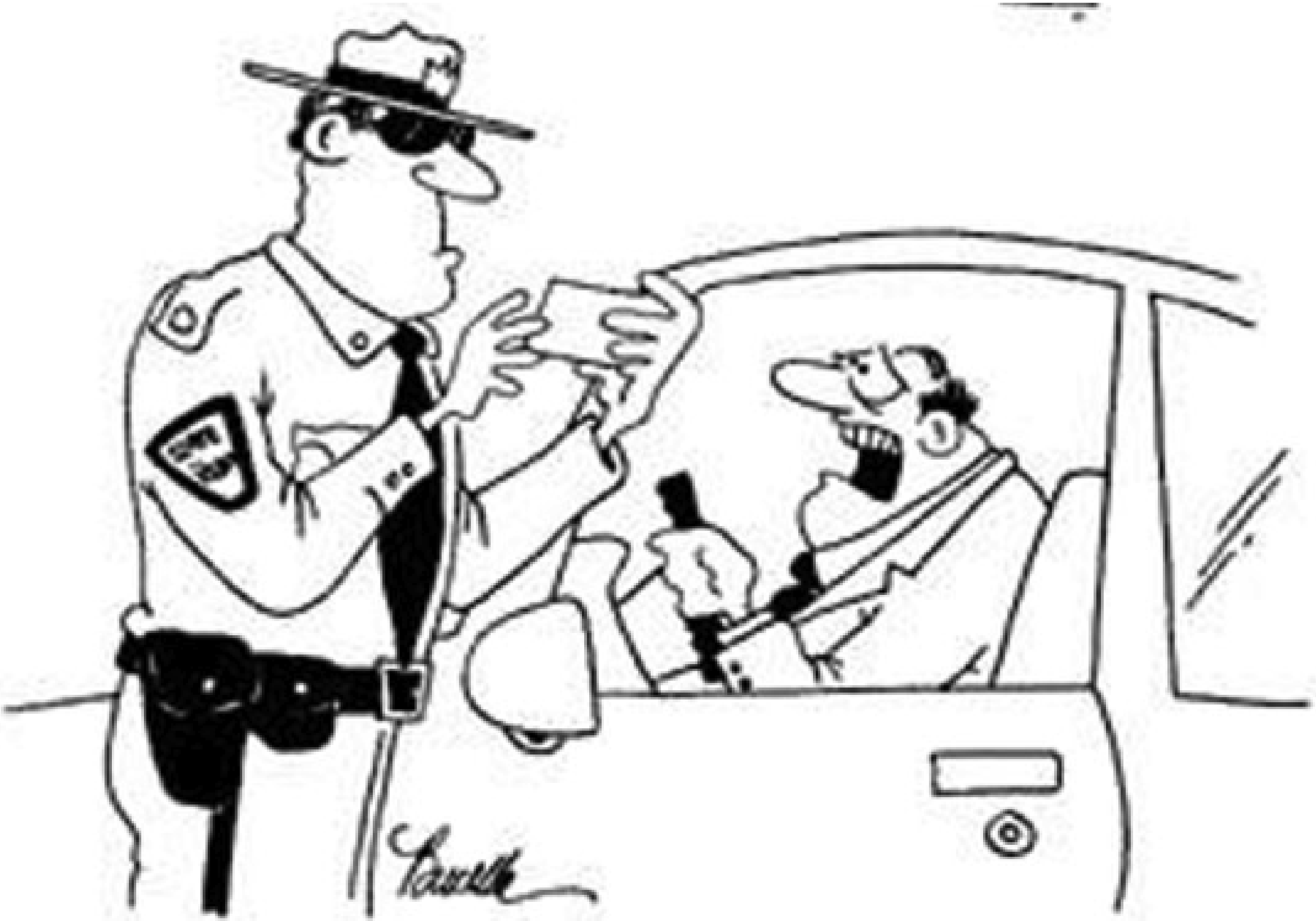
Are changes to working memory possible as a result of environmental experiences like digital? Possibly. Recent research has found that 'mental process training' seems to change working memory in adults. This research suggests changes to the working memory processes are possible through digital experiences. However, the memory training research has been challenged by a number of researchers (Makin, 2016).

Again, there are lots of opportunities for digital experiences to influence the working memory processes in young children given the time children spend surrounded by digital devices and media. How might this happen? Simply put, a practice effect—and a practice effect that often involves very challenging adult-like tasks!

A positive view of the practice effect suggests enhanced working memory development—and perhaps earlier development (age compression). Parents watching their 18 month-old child use a remote control to change programs would seem a testament. While there is no direct research to support changes in working memory, however there is no shortages of books and articles touting the enhanced cognitive abilities of our ‘i-children’ and ‘e-children’.

A negative view of this situation suggests that the hours and hours of digital experiences could over burden working memory and thus interfere with its development. This could lead to less ‘deep thinking’ and diminished long term memory capacity as well as a cognitive learning style that features constant shifts of working memory resources from moment to moment and task to task.

Speed and Efficiency of Information Processing



"Couldn't you have just called me on my cell phone and tell me to slow down?"

Speed and efficiency of information processing have been found to effect the development of reading and have been implicated in multiple language disorders (i.e., dyslexia).

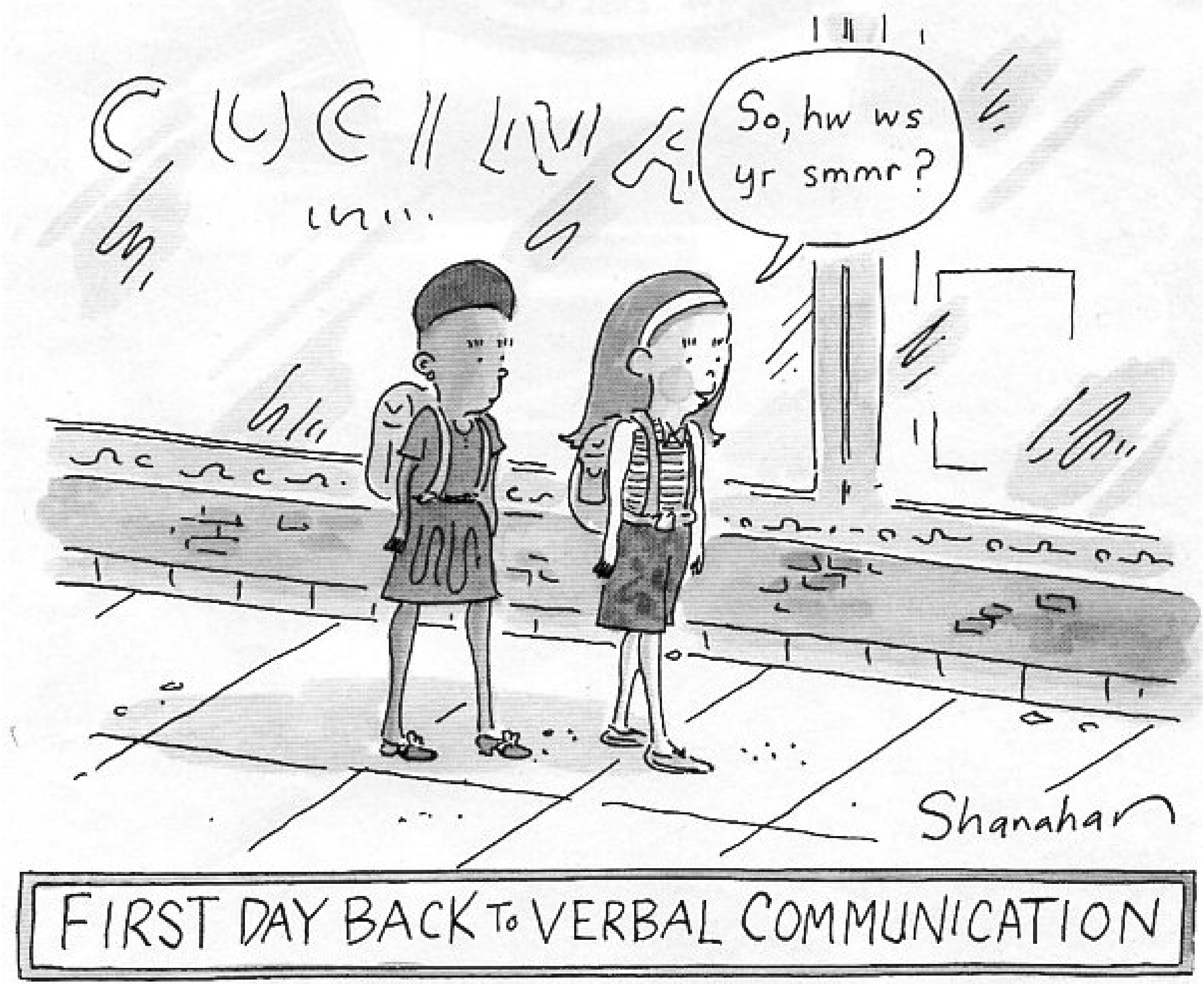
Research seems to indicate that young children are sensitive to information processing speed. For example, Stephen, McPake, Plowman and Berch-Heyman (2008) found that young children are sensitive to the speed at which information is presented and respond negatively to information that they find too slow as well as too fast.

Assuming that children are sensitive to information processing speed, a dilemma is apparent in today’s world of digital experiences. Children often encounter digital experiences by listening and watching older siblings and adults. These experiences appears at ‘adult’ processing speeds. Not surprisingly, children will likely encounter ‘adult’ speeds before they ever encounter slower developmentally appropriate ‘child’ speeds like those found in educational programs and formal classrooms.

A positive view of this situation suggests that as young children are surrounded by ‘adult’ speed content, they adapt to the expectations that things happen faster, with faster response and feedback times—along with faster information availability. They will also learn to adapt to slower speeds in settings specifically designed for their age. This could mean they will learn to make cognitive adjustments to the speed of information processing depending upon the circumstances indicating perhaps accelerated development or changes to brain mechanisms that are helpful to learning.

A negative view of this situation suggests that without the ability to make adjustments to information processing speed (a self regulation strategy as noted by Wartella and Richert, 2009), there could be delays to development or changes to the brain mechanism that are not helpful to learning—such as the inability to multitask.

Visual and Auditory Processing


So, hw ws yr smmr?
Shanahan
FIRST DAY BACK TO VERBAL COMMUNICATION

The **visual processes** enable the perception of visual forms and patterns---and perception is the application of meaning to a sensation. There is a long research history of visual process studies in reading (eye movements), but there is only a short history about digital experiences and visual processing. Many of the recent studies are behavioral studies about television viewing and game playing---and subsequent changes in the ability to detect and attend to detailed changes in visual stimuli (visual discrimination skill).

For example, Li, Atkins, and Stanton (2006) found that children who interacted daily with educational games on their computers improved their ability to attend and make detailed discriminations between visual images. Detailed visual discrimination is important because young children must attend to relevant differences in symbols such as between the a in pat and the o in pot---in multiple print fonts.

A positive view would again suggest a practice effect at work, that is, the more young children experience opportunities to develop detailed visual discrimination skill, the more likely it is to support reading development. This seems possible given the increased use and exposure to the variety of visual processing opportunities including the now wide-spread use of various small symbols and icons on devices like cell phones, smart phones, e-readers and tablet computers—all requiring detailed visual discrimination skills.

A negative view would suggest the same problems encountered with processing speeds, that is, if children cannot learn to rapidly and easily make detailed visual discriminations they will be at a disadvantage—perhaps delaying development or changing processes. This could be the case as ‘young’ eyes attempt to recognize and use adult small-sized symbol systems across a variety of fonts.

Auditory processing skills (auditory discrimination) are needed in learning to read. Not surprisingly, auditory processing deficiencies have been linked to atypical reading development and have been the focus of successful remedial efforts (Preston et al., 2016). Simply put, successful reading means the integration of circuitry between natural spoken language processes (auditory discrimination) and printed language processes (visual discrimination).

An important aspect of auditory processing in reading development is phonological discrimination. Phonological discrimination skills have been linked in neural imaging studies to the integration of oral language-print convergence needed for fluency and automated reading (Preston et al., 2016). Plainly stated, weak phonological discrimination skills---predict weak learning to read skills. So, how might digital experiences influence auditory processes?

As you have probably noted by now, there are no simple answers. Any meaningful auditory opportunities will influence the development of oral and listening language background: A key ingredient of learning to read. There is sufficient research evidence that young brains depend upon accurate, precise recognition of auditory details in individual and groups of sounds to develop oral and listening language background: Anything that introduces noise (competing sounds) can hinder development.

A positive view would suggest that if children have lots of opportunities to hear sounds in meaningful contexts as a result of digital experiences they might learn to rapidly discriminate between sounds---and tune in and out. However, a negative view would suggest that too much competition in the auditory stream (noise) could hinder discrimination development and children may not be able to tune in and tune out (White-Schwoch, 2016).

.

Semantic and Syntactic Cognition

The term **semantic cognition** refers to the ability to derive meaning, from words oral language and then print. An important part of deriving mean is drawing inferences (Kendeou, et al., 2016). Recent research indicates that digital experiences could hinder abstract inferencing but help concrete. In paper vs digital research, adults tended towards more detail inferencing with digitals and more abstract inferencing with paper (Kaufman, et al., 2016).

Syntactic cognition is related to auditory perception in the sense that children must develop the ability to derive rapid, accurate meaning of meaningful speech based on the rules of their language and detect rule violations. Simply put, in order to understand speech, children must develop auditory perception first and then sensitivity to the syntactic rules of their language.

Neuroimaging studies have begun to investigate syntactic cognition. Since auditory perception and syntactic abilities share resources in the quest to gain meaning (Hermann, et al., 2012), digital language experiences will impact syntactic cognition and the practice effect noted earlier will likely apply.

Clearly, the development of semantic and syntactic cognition, depend upon environmental language experiences—and children today have lots of experiences that come from digital sources. A positive view would suggest that children could get more educationally supportive oral language and print opportunities through digital media than was possible in the past. A case in point would be the Sesame Street educational TV studies.

However, there is a large body of research that documents the importance of diverse and in-depth meaningful oral and listening language experiences as well as print awareness in reading development. If children's digital experiences lack educational significance or value for the development of reading, then, the hours of digital experiences that children accumulate on a daily basis will help---and could even hinder reading development.

What Might All Of This Mean For Teachers?

Attention, working memory and self-regulation seem to be the most probable candidates for change. If teachers suspect a problem, here are a few suggestions!

For <u>attention</u>, perhaps gradually increase the time-on-task demands needed for class activities—gradually lengthening the time across the school year.

For <u>working and long term memory</u>—gradually increase the need for children to employ previous experience or background knowledge demands in your classroom activities. This is where constant references to the children's previous experiences—in and outside your classroom—might help. Also, exercise working and long term memory in class through memorization activities.

For self-regulation, it is important to remember that children develop self-regulation skills through in-school as well as out-of-school experiences. Today many of these self-regulation experiences involve digital devices and media.

Self-regulation is difficult to TEACH and as a result children develop self-regulation through tasks that demand self-regulation.

Teachers need to familiarize themselves with the self-regulation experiences children face each and everyday in the digital world. So, stay ‘in touch’ with the digital experiences of your children and how they are learning through those experiences. Also, provide self-regulation tasks in the classroom that support not only classroom curriculum but also the daily out-of-school digital experiences of children.

In conclusion, the current state of research and practice suggests the following about possible changes to the neural processes responsible for learning to read.

Hypothesis A is rejected, and B as well as C are accepted as likely and Hypothesis D is accepted as possible. For the future, if there were an Hypothesis E, it would suggest possible changes to genes----from an early life full of digital experiences.