

## Memory/Working Memory

Here is an interesting study on timing in the brain by Botzung et al (2008). Timing in the brain (or what scientists refer to as precisely timed neural transmissions or neural oscillations in and between brain regions) is critical for humans to be able to store and retrieve memories. As an added dimension, humans have the ability to think ahead into the future and imagine being there. Their minds can also travel back in time to distant memories, which at times may feel like they just happened yesterday.

Researchers were curious about how the brain travels along this time continuum, or what brain structures are involved. They specifically wanted to know whether the same brain structures and mental processes are involved in going forward and back in time. To investigate this further, they employed fMRI (functional magnetic resonance imaging) to look into the brains of several individuals while performing these mental activities. They found that similar brain structures and processes are used in both types of mental time travel and that, perhaps most interestingly, our past memories and experiences allow us to project into the future to imagine events that have not yet occurred. Some individuals demonstrate less ability or propensity to think into the future or plan ahead due to a developmental problem or brain injury. They might be considered a little (or a lot) impulsive. There may be safety issues (i.e., acting before thinking about what happened the last time they tried to do something particular!) Interactive Metronome (IM) is a therapy tool that many professionals are now incorporating into programs for ADHD, Autism, Traumatic Brain Injury, Stroke, and other developmental and acquired disorders to improve timing in the brain. IM measures and improves timing in the brain necessary for planning/anticipating future events and thinking before acting.

*Botzung, A., Denkova, E., and Manning, L. (2008). Experiencing past and future personal events: Functional neuroimaging evidence on the neural bases of mental time travel. Brain and Cognition, 66, 202-212.*

The human brain keeps time. Time is essential for understanding & producing intelligible speech, focusing attention, for reading, writing and other academic skills, and the list goes on and on... According to scientists, we must focus and engage our attention, control what we are focused on, tune out distractions, and hold & update information about the task in working memory in order for the brain to do the work of keeping time accurately. One of the predominant theories about how the manages time-related information is called the "pacemaker accumulator model." This theory suggests that our brain emits timed neural impulses until a certain number are accumulated (equaling a target duration of time, in milliseconds). Each time the brain handles information, the electrical circuits and impulses get to work and must do so in a very precisely timed, synchronized manner. When a short-circuit happens or there is not the level of precise synchronization or coordination of signals within and between centers of the brain, it shows in our performance on mental and physical tasks (i.e., ability to focus, to understand and follow directions, to read, to

spell, organize thoughts, produce language, and write legibly, and to coordinate motor movements for walking, running, jumping, climbing....) Fortunately, timing in the brain is a skill that can be shaped and improved with specific training. Key to training is “feedback” so you know what you are doing wrong and can correct it. The Interactive Metronome is the ONLY brain fitness tool that provides feedback for timing in the brain each and every move, allowing you to progressively get more and more precise. More precise timing leads to improvement in the problem areas listed above.

*Fortin, C. (1999). Short-term memory time interval production. International Journal of Psychology, 34(5/6), 308-316.*

Here is another study, one of MANY, that show a clear relationship between working memory and timing in the brain (Fortin et al., 2007). Essentially, if timing in the brain is disrupted, then working memory does not work very efficiently or effectively leading to a host of problems at home, school, work, and play. If you’ve been searching the internet for a program or treatment to address school performance, a developmental delay or disorder, or overall brain fitness, then you’ve surely seen all the buzz about the importance of working memory for cognitive performance. Given the importance of timing in the brain for working memory, and thus cognitive performance, it is critical to assess timing in the brain to see if that is the root of the problem.

Interactive Metronome is a patented program that both assesses and improves timing in the brain, providing measurable scores each step of the way. Persons may then derive more benefit from the various cognitive fitness programs available once his/her brain is focusing, processing information, and utilizing cognitive resources like working memory more efficiently and effectively.

*Fortin, C., Champagne, J, and Poirier, M. (2007). Temporal order in memory and interval timing: An interference analysis. Acta Psychologica, 126(1), 18-33.*

What we can probably say for certain is that the brain does keep time; precisely HOW it does that is still up for debate. There are several predominant theories that are keeping many researchers busy! Here, Rosenbaum (2002) puts forth yet another theory. Have you read the literature on mental timing theory? What do you think? Regardless of how the brain does it, we know that a person can improve timing in the brain with specific practice. Interactive Metronome improves timing in the brain through progressive exercises & feedback that can be customized to suit the needs or interests of the individual (i.e., practicing repetitive movements for self-feeding or self-care, or simulating sports or incorporating play).

*Rosenbaum, D.A. (2002). Time, space, and short-term memory. Brain and Cognition, 48, 52-65.*

According to current research, individuals that have greater capacity for

holding information and keeping it updated in working memory also have greater ability to focus and direct their attention. Essentially, if working memory is functioning efficiently, the brain doesn't have to devote so much of its resources to making it work. This in turn frees up the person to devote cognitive resources to other tasks. Colflesh & Conway (2007) found further evidence for this, or what is called the "controlled attention theory of working memory." Not surprising, they also found that those with greater working memory capacity were also better multi-taskers. Working memory, which is one of several brain functions associated with our internal mental clock, can be improved by addressing underlying deficiencies in neural timing (or timing in the brain) with Interactive Metronome.

*Colflesh, J.H. & Conway, R.A. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. Bulletin & Review, 14(4), 699-703.*

Fink and Neubauer (2005) showed that more intelligent (or "brighter") individuals perform better on cognitive tasks for two reasons: 1) they have more capacity in working memory (the ability to hold and manipulate information in temporary memory storage) and 2) their brain can process information more rapidly. They demonstrated that those individuals with higher intelligence, as a result of these two factors, have a tendency to estimate time much more accurately. Researchers (Taub et al., 2007) theorize that "cross-domain effects" of Interactive Metronome training (or its effect on so many different cognitive and motor abilities) may be attributed to its effect on these critical skills: attention, processing speed, and working memory.

*Fink, A, Neubauer, A.C. (2005). Individual differences in time estimation related to cognitive ability, speed of information processing and working memory. Intelligence, 33, 5-26.*

Our ability to control what we pay attention to, when, why, and how long has been given several names, including: the supervisory attention system, executive control, or the central executive. No matter what it is called, researchers feel it is critically important to be able to focus and direct our attention in order to have adequate mental resources in working memory to perform everyday cognitive (thinking) tasks. In this article, Barrett et al (2004) do a thorough job describing in detail exactly what is involved in both the attentional control system and working memory and how they influence how we think and perform cognitive tasks. It is interesting how some researchers find this relationship between attention and working memory to be reversed, that greater working memory capacity enables the individual to focus and direct attention better. More importantly, we can see from the literature that the abilities of attention and working memory (and I might add information processing speed) are critical good cognitive performance (i.e., academically, professionally, interpersonally). The neural basis for each of these skills is "temporal processing," or timing in the brain. According to a

mental timing theory proposed by several scientists, processing speed and working memory share a limited pool of cognitive resources. When information processing is slowed or inefficient, working memory suffers and the person then has less attentional resources to devote to tasks. After studying the effect of Interactive Metronome (IM) on reading achievement, Taub et al (2007) proposed that IM training increases our brain's clock speed or temporal processing (the ability to process information more rapidly and fluently) thereby increasing the efficiency of attention and working memory. This in turn leads to better cognitive performance.

*Barrett, L.F., Tugade, M.M., and Engle, R. (2004). Individual differences in working memory capacity and dual-process theories of the mind. Psychological Bulletin, 130(4), 553-573.*

In this study by Baudouin et al (2006), elderly individuals estimated the amount of time that elapsed in 2 different tasks: 1) producing an amount of time when told to, 2) copying an amount of time after being shown. Steps were taken so that they could not count or use other strategies to track time. This study showed that performance was dictated by the individual's internal clock rate. Some had faster clock rates; they tended to produce shorter time intervals (shorter than the amount of time they were asked to present). This has implications for rehabilitation. I can recall more than one patient that needed the tempo (or speed) increased when completing Interactive Metronome training as part of their overall rehabilitation following neurological insult (stroke, Parkinsons, etc) because they just could not slow down. These individuals tended to be inattentive, impulsive, and exhibited memory and other cognitive impairments. By starting at their internal clock speed (at a higher tempo), I was able to get a foot in the door and from there modulate them gradually down to a slower tempo or clock speed where they could function better & more safely in various environments with timing that was more in sync with their surroundings (i.e., for ADLs, ambulation, reading, conversation, community outings, etc). Interactive Metronome is a flexible timing intervention that addresses the basic foundation for safety judgment and functional independence, that of internal clock speed or what is known as "temporal processing."

*Baudouin, A., Vanneste, S., Isingrini, M., and Pouthas, V. (2006). Differential involvement of internal clock and working memory in the production and reproduction of duration: A study on older adults. Acta Psychologica, 121, 285-296.*

For those of you who are now so intrigued with working memory that you want to go out and measure it, this article is for you! Conway et al (2006) describe in detail what working memory is, the various ways it is measured, and the validity of each measurement tool. The Interactive Metronome is a timing intervention that affects working memory and its close cohorts, processing speed and attentional control. This is valuable information if you are considering a research study of your own on the effectiveness of the

Interactive Metronome for reading achievement, relieving symptoms of ADHD, or some other application.

Conway, Andrew R.A., Kane, M.J., Bunting, M.F., Hambrick, D. Zach, Wilhelm, O., and Engle, R.W. (2005). *Working memory span tasks: A methodological review and user's guide. Bulletin & Review, 12(5), 769-786.*

In time estimation, memory for past event durations is critical to our ability to judge the duration of events happening in the present. We hold this information about duration (or time associated with various events, actions we have experienced) in a "temporal reference memory" so that our brain can compare: is this new event the same duration as what I experienced last time, shorter, longer? This paper by Delgado & Droit-Volet (2007) describes the most current theories about how our brain keeps time (i.e., scalar timing theory, pacemaker-accumulator model). Good reading if you are interested in getting to this depth about timing in the brain and how it is important for all of our human capabilities. The authors show further evidence that our brain not only measures time, but that this ability gets better as we age (i.e., children show less accuracy than adults). This is an interesting finding. Normative data from Interactive Metronome, a patented timing technology that measures and improves temporal processing, shows that timing in the brain improves as we age.

Delgado, M.L. & Droit-Volet, S. (2007). *Testing the representation of time in reference memory in the bisection and the generalization task: The utility of a developmental approach. The Quarterly Journal of Experimental Psychology, 60(6), 820-836.*

There is much interest these days in studying children's ability to estimate time, particularly those between the age of 3 and 10. Why? This research may help us better understand how the brain's ability to keep time develops as the child ages, especially as children across successive age groups are studied and are compared to adults. In this study, Droit-Volet and colleagues (2007) saw that younger children (around 5 years of age) had less sophisticated working memory capacity and therefore were more prone to errors in time judgment. We do see this in reality, where younger children are less able to manage time. It is definitely a skill that blossoms as the child ages, thankfully!! However, due to developmental disorders, this timing skill does not always develop normally and some children have lesser ability to measure or manage time. This leads to a variety of different presentations: reading disorders, speech and language disorders, hyperactivity, impulsivity, auditory processing disorders, etc. Interactive Metronome (IM) is a treatment program designed to improve timing in the brain that is flexible and can be completed in a clinic with the guidance of a professional/therapist or in the home with a virtual coach. Following IM training, participants frequently report improved performance in reading and other academic skills, more control of behavior and aggression, increased cooperation and participation, and further development of speech &

language skills. Interactive Metronome training provides the foundation of timing in the brain. It is most effective when combined with specific training to build skills that are developmentally lagging (i.e., intensive reading instruction).

*Droit-Volet, S., Wearden, J., and Delgado-Yonger, M. (2007). Short-term memory for time in children and adults: A behavioral study and a model. Journal of Experimental Child Psychology, 97(4), 246-264.*

Here again, Field & Groeger (2004) show the intimate relationship between working memory and timing in the brain or “temporal processing.” In the discussion, it is noted that previous research has shown that when we hold AND manipulate information in our working memory (i.e., making a mental comparison or problem-solving) and we ADD an additional mental task to working memory (or increase “cognitive load”), this new information interferes with the information being held in memory for the first task. In this study, the authors show that when we simply HOLD information in working memory but do not actively manipulate it for a purpose and then ADD another mental task (again, increasing “cognitive load”), the second task information ALSO interferes with first. When we talk about “interference,” we mean that information about the first and second task get confused with one another or that the second set of information causes some of the first to be forgotten or recalled inaccurately. We see this quite a bit after concussion or traumatic brain injury where the person can recall the information, but the information gets mixed up. Here is an example: The person may be told at the same time that he has a doctor appointment on Tuesday @ 1:00 and a hair appointment on Friday @ 4:15. He may recall this after a short time delay and intervening activity as a hair appointment on Tuesday @ 1:00 and a doctor appointment on Friday @ 4:15. Interactive Metronome is a treatment that addresses the underlying timing deficit in working memory, improving the ability to process, store, and retrieve information more accurately.

*Field, D. T. & Groeger, J.A. (2004). Temporal interval production and short-term memory. Perception & Psychophysics, 66(5), 808-819.*

In this study (Hall & Blasko, 2005), the authors show further evidence that the less prone to distraction a person is, the better his working memory will operate. Why is this important? Because working memory is linked to a whole host of cognitive abilities...it may be considered a gateway or bottleneck for higher level thinking, memory storage and retrieval, and learning. Interactive Metronome is a timing intervention that works at the core of our thinking, at the level of attentional control, processing speed, and working memory...skills that are governed by our internal mental clock. Training takes a comparatively short period of time to complete (weeks) and can be completed in a clinic setting with professional guidance or in the comfort of your home with a virtual coach.

*Hall, M.D. & Blasko, D.G. (2005). Attentional interference in judgments of musical*

*timbre: Individual differences in working memory. The Journal of General Psychology, 132(1), 94-112.*

Palladino et al. (2003) studied 20 subjects to determine whether there was a difference in how the brain handles information when it is presented verbally versus visually. They did find that there is a difference in processes involved in working memory depending on how the information is presented. Complex thinking involved in tasks like reading comprehension depend upon working memory. It has been reported that working memory is very sensitive to intrusion errors (or corruption from information that is not relevant to the task at hand that enters the mix). Humans possess a very important skill called inhibition, which is the ability to filter information to only keep in active working memory what is important to the task and discard the rest. Filtering may not occur if the person cannot selectively attend to incoming information, mentally manipulate information for comparison, and/or keep up with the pace of incoming information (slower processing speed). Many studies have reported on the central role of “temporal processing” or timing in the brain in working memory. Researchers who studied the Interactive Metronome (IM) specifically, a patented program that improves timing in the brain, theorize that IM improves timing in the brain by increasing the flow and efficiency of information processing, an important precursor to working memory function.

*Palladino, P., Mammarella, N., and Vecchia, T. (2003). Modality-specific effects in the inhibitory mechanisms: The interaction of peripheral and central components in working memory. Brain and Cognition, 53, 263-267.*

In this study by Sayala et al (2006), researchers viewed the brain with neural imaging during a problem-solving task. Even though the problem was presented verbally (and no visual information was supplied or used in the process), the person engaged several areas of both sides of the brain in order to solve the problem, including the visual cortex. They also pointed out that working memory was responsible for maintaining and updating information about the problem to be solved and helped to serve in the capacity of a visual-spatial sketchpad. Many studies now show that the ability to maintain and update information in working memory, while tuning out information that is not relevant to the task (intruding thoughts or external distractions), is governed by the timing of neural oscillations or transmissions (or what is commonly referred to as temporal processing). Synchronization is the key to optimal timing in the brain. Studies show that individuals with disorders like ADHD, Autism, Dyslexia, and Parkinsons tend to display deficient mental timing. Interactive Metronome is a specific training program that measures and improves this synchronization through progressive exercises that fun, yet challenging while they engage the whole mind and body.

*Sayala, S., Sala, J.B., and Courtney, S.M. (2006). Increased neural efficiency with repeated performance of a working memory task is information-type dependent.*

*Cerebral Cortex*, 16, 609-617.

The rate & synchronization of timing in the brain have a great influence on our ability to control our attention, direct it where it needs to be, tune out distractions, maintain and update information about what we are supposed to be doing “right now” in working memory (“inhibition”), and, of course, make all this happen seamlessly without hiccups. In this study, researchers provided further evidence that working memory is central to our ability to function in the world and that it is greatly affected by how well we can direct the focus of our attention. Those that have more of a problem with focus have more trouble recalling information accurately or at all about what they are supposed to be doing at the moment. Do you know anyone with this trouble? It is quite common these days with the increase in childhood developmental disorders and the increase in Traumatic Brain Injury and Concussion as a result of the ongoing wars in Iraq and Afghanistan. Interactive Metronome, a treatment tool that improves timing in the brain, is currently used to help children overcome learning obstacles and at multiple VA hospitals with our veterans who have difficulty with focus, memory and other cognitive difficulties that interfere with their functional independence upon return to civilian life. We thank them for their service to our country and wish them all the best in their recovery!!

*Unsworth, N., Schrock, J.C., and Engle, R.W. (2004). Working memory capacity and the antisaccade task: individual differences in voluntary saccade control. Journal of Experimental Psychology: Learning, Memory, and Cognition, 30(6), 1302-1321.*