IMPROVEMENTS IN INTERVAL TIME TRACKING AND EFFECTS ON READING ACHIEVEMENT
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The Master Mental Clock and Cognitive/Neuropsychological Constructs
The major components of PAM-based mental interval timekeeping have strong similarities to a number of domain-general cognitive mechanisms featured in contemporary cognitive information processing and/or neuropsychological research. Working memory, which is pivotal to PAM, is a central concept in major models of information processing. In addition, the PAM long-term (Buhusi & Meck, 2005) memory likely invokes early stages of memory consolidation in longterm memory or storage, another major component of information processing models of cognition. Furthermore, the if-then decision-making function of the PAM comparator is a function typically associated with skills involved with executive functioning (e.g., monitor, evaluate, change). Finally, research has implicated the important role of attention during the cognitively controlled portions of interval timing (Buhusi & Meck, 2005). Therefore, it is hypothesized that a conceptual cross-talk between the major components of the PAM master internal clock and contemporary cognitive information processing theories suggests that SMT performance and SMT transfer effects result in an increased efficiency in the functioning of the domain-general cognitive information processing mechanisms of (a) working memory, (b) executive functioning, and/or (c) controlled or executive attention.

Working Memory, Executive Functioning, and Executive Controlled Attention
Executive functioning (EF), which is also frequently called the central executive system, is a term used for a broad construct that represents a cluster of skills necessary for efficient and successful goal-directed behavior (Welsh, 2001). The EF constructs of planning, monitoring, inhibition, and attention/concentration, elicit a range of basic cognitive processes (e.g., attention, perception, language, and memory) that are coordinated for a very specific purpose: subserving goal-directed behavior. EF processes are believed to work in symphony to facilitate goal-directed task completion. Timing and processes related to mental timing are believed to be a component of executive function (Welsh, 2001), as is the utilization of executive functions during reading performance (Bull & Scerif, 2001). Because EF is an integration of a constellation of abilities necessary for the planning, self-monitoring/ regulating, and evaluation of successful task completion, the area of selfregulated learning has received considerable attention with regard to a variety of cognitive activities (e.g., meta-cognition, pre-attentive processes, sluggish attentional shifting, specific strategy selection and implementation, inhibition, multitasking activities, task switching, maintenance of information under conditions of interference, and resistance to interference; Bull & Scerif, 2001; Borkowski, Carr, & Pressley, 1987; Kane, Bleckley, & Conway, 2001). The central role of EF in the enhancement of selective or controlled attention, the ability to switch between plans and strategies, and the inhibition of task-irrelevant information (intrusions) in working memory (Engle, Tuholski, Laughlin, & Conway, 1999; Passolunghi & Siegel, 2004) is consistent with theoretical and descriptive interpretations of SMT and interval time tracking models. It is proposed that the executive controlled attention model of working memory (Engle, Kane, & Tuholski, 1999; Kane, Bleckley, Conway & Engle, 2001), which invokes the EF system, should be entertained as a potentially useful initial model to explain the domain-general effects of SMT-based interventions. Briefly, the executive controlled attention working memory model hypothesizes that individual differences in task performance are related to EF controlled attention. This means that individuals with higher working memory demonstrate better (or more efficient) use of attentional resources and are more able to resist interference during the encoding and
retrieval processes than individuals with lower working memory. It is our hypothesis that SMT training does not improve working memory by increasing capacity, rather that SMT training may result in more efficient use of an individual’s working memory system. The central role that the general capability to efficiently process information plays in task performance is consistent with a general mechanism explanation for the diversity of across-domain effects of SMT training. Central to the controlled attention working memory model is the role of EF. The alternative working memory view, which argues more for emphasis on underlying modality-specific working memory subprocesses (Palladino, Mammarella, & Vecchi, 2003), in contrast to resource-sharing models, presents a much more complex alternative model by which to explain positive SMT training effects across such diverse performance tasks (although it would be inappropriate to completely discard it as a possible explanation at this time). The search for a domain-general mechanism to explain SMT generalized training effects, such as the controlled attention working memory model, represents a more parsimonious approach that is believed to be preferred as formative attempts are made to describe and explain SMT training effects.

Finally, the recent suggestion that general intelligence (the most enduring and robust domain-general cognitive mechanism in the history of the psychometric study of intelligence) may be more a function of temporal processing and not necessarily reaction time (as measured by the traditional Hick paradigm; Rammsayer & Brandler, in press) suggests that mental interval timekeeping models (e.g., PAM) may describe and explain a primary elementary cognitive mechanism involved in most all complex human behavior. If temporal g exists, then the across-domain positive treatment effects of SMT training might be explained as the improvement of general neural efficiency via greater resolution of the temporal g internal clock.

Summary

This study investigated the effect of a SMT training intervention on elementary-school-age students’ reading achievement. The observance of statistically significant improvements in the experimental group’s performance on posttest measures of reading, when compared to the control group, is impressive given the nature of the nonacademic intervention. Yet, the results are not conclusive and are inconsistent in some cases. For example, the elementary school students scored significantly better on a timed single word recognition test, yet, there was no significant betweengroup difference on a measure that required reading short simple sentences (WJ-III Reading Fluency). Also, previous research with high school students reported a statistically significant relationship between SMT improvements and reading fluency. One possible explanation for the divergent developmental intervention effect findings is that elementary school students are learning how to read, whereas high school students are reading to learn. In other words, high school students have mastered or automatized their reading skills, whereas the elementary school students are learning how to read.

Nevertheless, the automatization of critical early reading skills (viz., phonics, phonological awareness skills, and RAN performance), which emerge primarily during the early school grades, are the specific areas where the elementary-aged experimental participants demonstrated the most significant improvements in the current study. It is also possible that studies (the current study, inclusive) that have reported improvements in timing and rhythmicity over short periods (3–4 weeks) may only demonstrate significant effects on the processing of overlearned (automatized) information, in contrast to the more deliberate or controlled learning of new information. This may also explain why golfers, who presumably have overlearned their golf swing, become more accurate with improvements in timing/rhythmicity.

It is believed that subcomponents of the constellation of executive functioning are effected by SMT interventions. Because of the cross-domain influence of working memory on task completion, the executive controlled attention model of working memory, which is heavily dependent on the executive functioning system, was hypothesized as a potentially useful model for conceptualizing SMT research and for interpreting research findings. The executive controlled aspect of working memory was suggested as a possible general cognitive mechanism responsible for the observed positive influence of SMT training across such diverse domains as academics, athletics, and attention/concentration.