12-5-2009

# Temporal Awareness and Rhythmic Performance

Daniel J. Colombo

**Rochester Institute of Technology**

**College of Liberal Arts**

**Department of Psychology**

# TEMPORAL AWARENESS AND RHYTHMIC PERFORMANCE

**A Thesis in**

**Applied Experimental and Engineering Psychology**

**by**

**Daniel J. Colombo**

**B.S., SUNY Brockport, Psychology, 2005**

**Submitted in Partial Fulfillment of the Requirements for the Degree of**

**Master of Science**

**December 5th, 2009**

We Approve the Thesis of Daniel Colombo | Date of Signature

Esa M. Rantanen, Ph.D.
Associate Professor, Department of Psychology
Thesis Adviser and Chair of the Thesis Committee

Andrew M. Herbert, Ph. D.
Associate Professor and Chair, Department of Psychology
Reader

Carl Atkins
Professor, Director of Music, Department of Fine Arts
Reader

**Abstract**

The objective of this research was to study the conditions under which rhythmic behavior arises and its effects on task performance and mental workload. It has been demonstrated that temporal awareness (TA) in dynamic systems draws on high-level mental resources and contributes to superior performance on some task elements but not others. Elsewhere it has been demonstrated that TA in environments with high predictability can lead to superior task performance and reduced mental workload. This research sought to examine the behavior and subsequent performance that arises under highly predictable vs. dynamic conditions. Using a computer-based time-sharing task, we analyzed task performance and temporal awareness under 3 levels of rhythm (easy, difficult, and arrhythmic) and 2 levels of response task difficulty. Results indicate that rhythmic presentation of both response task levels leads to reduced levels of mental workload, but offers no discernible benefits to task performance. Participants exhibited greater TA in rhythmic conditions as compared to arrhythmic conditions. Further testing with more realistic response tasks and a greater balance in rhythm levels is needed to more accurately describe participants' subjective experience of rhythm and its effects on task performance.

## Table of Contents

## List of Figures

## List of Tables

**Acknowledgments**

I would like to acknowledge and thank my advisor, Dr. Esa Rantanen, for his encouragement and guidance throughout the thesis process. Due to my remote location about 1400 miles from RIT, it would have been very easy for him to ignore me and focus on the squeakier wheels, but I received copious amounts of instruction and feedback nevertheless. Thanks are also due to my committee members, Dr. Andrew Herbert and Professor Carl Atkins, whose comments on an initial draft proved invaluable leading up to the defense and final iteration of this document. I would also like to thank my manager at SA Technologies, Inc., Ms. Laura Strater, for not accusing me of disingenuousness when I missed my projected master's completion window by about a year, and my colleague at SA Technologies, Dr. Sandro Scielzo, for trying out his experimental "shame-based" motivation program on me (which turned out to be remarkably effective). Special thanks to my parents for their continued love and support, and to my fiancée Allyson Hall, for being a smarter person in the room that I could always turn to for advice.

# Chapter 1: Introduction

Real-world examples of rhythmic behavior abound: the parent pushing their child on a swing absent-mindedly while carrying on a conversation with another parent two swings over; the orchestra conductor who maintains precise rhythmic motion of the baton while signaling her orchestra as to a forthcoming crescendo; the basketball player who dribbles the ball automatically while maintaining awareness as to the location of teammates and the opposing players. But consider also the many ways in which rhythmic actions can lead to overconfidence or complacency in one's tasks. One such instance was the mortar accident at the Rovajarvi shooting zone in 2005 (Accident Investigation Board, 2007). A seven-member mortar crew (1 leader, 1 loader, 1 charger, 2 pointers, and 2 ammunition carriers) was attempting to fire nine mortar rounds in a 60s period. After confusion ensued between the leader, loader, and charger about how many rounds had been fired to that point, the $7^{th}$ and $8^{th}$ rounds were double-loaded, and they subsequently exploded, killing one and wounding several others. Of particular note in this scenario is the high skill-level of the crew and the highly regular intervals in which the actions occurred. The high skill-level of the crew allowed them to perform their tasks in an automatic, *feedforward* fashion, and the highly regular intervals in which the unit worked likely led to the acquisition of a strongly entrained rhythm.

The purpose of this research was to investigate the factors that may allow for emergence of automatic performance, whether such performance could be classified as rhythmic, and the effects of such performance on both temporal and nontemporal task elements. These questions were examined experimentally, using multiple simple tasks that were to be performed in a certain order in time and by manipulating the regularity of the task sequence and the difficulty of the task. Several objective and subjective measures of participants' performance and experienced workload were analyzed.

### *Temporal Awareness*

Temporal awareness (TA) can be defined as the awareness of the temporal unfolding of events, their temporal relationships (e.g., before, after, simultaneity) and the time intervals between them. A good TA may help operators to successfully diagnose the causes of one's current state based on past events, coupled with the ability to successfully predict possible future states based on that data. This definition presupposes that the operators possess a valid mental model of the systemic elements of their task, and is more in line with the notion of TA as an important component of situation awareness (SA) than as a mere descriptor of perceived duration (e.g., Endsley, 1995; Rantanen, 2007; Sarter & Woods, 1991). Rhythmic performance will be defined here as behavior that arises in repetitive, well-practiced tasks, and can be characterized as more or less automatic. This behavior always occurs along the temporal dimension and depends heavily on system components behaving in stable and predictable ways.

Human behaviors and psychological processes can be described as automatic or controlled; automatic actions occur in an open sensory-loop (no visual feedback required) and are characterized by low attenional demand (Wickens & Holland, 2000). A series of actions can be described as feedforward if the operator does not have to wait for feedback but can instead move on to the next task with some confidence as to the outcome of previous actions. Automatic tasks are subject to specific error types that are quite different from those errors occurring in higher-level operating modes (Reason, 1990). Reason's Generic Error Modeling System (GEMS) (1990) provides a taxonomy of human errors that take place within Rasmussen's skills, rules, and knowledge (SRK) framework (1983). This framework is essentially a guide for describing how automatic or controlled one's actions are. The skill-based operating mode is automatic and actions are carried out in an open sensory loop with little or no conscious attention. In the rule-based mode, the operator has realized that the routine action will not go as planned, so an if *x* then *y* strategy is applied, which if executed properly facilitates the move back to a skill-based mode. Finally, the knowledge-based operating mode is an iterative process in which novel problem situations arise that cannot be resolved using known rule-based strategies. In this highly controlled mode, patterns must be identified, goals formed, plans for carrying out these goals, etc. This is a costly, time-consuming, and necessarily sequential operating mode that breeds errors of its own. Errors occurring in automatic or skill-based modes are deemed to be *slips*, and result from the failed execution of appropriate actions due to misplaced attention. Errors occurring in rule- or knowledge-based modes are tabbed *mistakes* and result when an inappropriate plan is selected to remedy some problem (Reason, 1990).

Grosjean and Terrier (1999) found that subjects who developed a strong temporal awareness generally committed fewer control errors and used their rest periods more efficiently, but their performance on a low-level rote copying task suffered relative to participants who did not develop TA. Using Rasmussen's SRK framework (1983) to explain this disparity, Grosjean and Terrier concluded that performance factors that benefited from TA drew on high-level resources, and thus required a knowledge-based operating mode.

Though the development of TA as defined by Grosjean and Terrier (1999) is a "superior" strategy in terms of avoiding errors in dynamic, knowledge-based tasks, it would be lamentable if decisions based on knowledge of the temporal relationships between shifting task elements were incapable of becoming streamlined into less resource-exhausting skill- or rule-based modes. It is instead likely that TA of dynamically and rapidly changing tasks must be performed in a knowledge-based mode, and those tasks which present some stability, however subtle, can be performed rhythmically, or with a skill-based TA.

Evidence for this comes from Okada (1992), who found that using an acquired rhythmicity to perform a complex flow-line changeover in a simulated nuclear power plant (NPP) was in many ways superior to performing the procedure according to protocol. Rather than maintaining in working memory dynamic information concerning water-levels, temperatures, and steam pressure, participants were able perceive a specific rhythm by which they could switch control lines that was at least as effective as the prescribed strategy. This facilitated the acquisition of a mental representation of the line changeover process, and subjects were able to perform even "unstable" condition tasks with minimal cognitive strain. Although subjective workload measurements were not taken, it is likely that rhythmic operation reduced cognitive strain and thus implies a skill-based operating mode. Okada (1992) is one of the few examples of rhythmic operation in the literature; De Keyser (1995) described one instance of a thermo-electric plant operator gaining knowledge of the system state by using temporally-sensitive markers that arise as by-products of normal plant functioning, but it is unclear whether these markers occur with enough regularity for a clear rhythm to be established. Evidence for perceived or acquired rhythm being dissociable from higher level cognitive functioning comes from more basic literature in a variety of domains. This paper will present evidence from both early and recent sources in the domain of psychological rhythm, as well as neurological models that may explain how acquired rhythmicity can be dissociated from higher-level processes (Ivry, 1996; Zakay, Block & Tsal, 1996).

***Early Research on Rhythm***

Psychologists have been interested in the phenomenon of rhythm for over a century. Bolton (1894) reported that subjects naturally grouped monotonous clicks into groups of 4 or 8, despite the fact that the clicks were uniform in terms of pitch, timbre and presentation time. Shortly thereafter, MacDougall (1900) conceived of several introspective notions of the nature of rhythm, which, though not empirically verified at the time, provided a useful framework in which to study rhythm. McDougall parsed rhythm into three separate areas of study, the subjective experience of rhythm, the objective factors of rhythm (physical characteristics of the sounds), and the aesthetic value of rhythmic art forms. This classification scheme yielded two fundamental ideas that are especially relevant to the topic of rhythmic behavior, (1) the notion that subjective rhythmization occurs only when the successive elements of rhythm are not "specially attended to" (MacDougall, p.309), and (2) that the "series of sounds must be listened to for a certain time before subjective rhythmization arises" (MacDougall, p. 310). On the former point, rhythmic control would not benefit from an allocation of "special" attentional resources to the rhythmic elements, as the principle advantage of rhythmic control is the lack of strain on working memory. Likewise, the notion of "rhythmization" being induced only after exposure to the rhythmic elements for a brief period is consistent with modern internal clock theories such as that of Zakay and Block (1994), as well as the more applied findings of Okada (1992).

Isaacs (1920) composed an early review of the rhythm literature and concluded that while humans possess no specific sense or organ for the detection of rhythm, the collective beating, pulsing, heaving, etc. of the involuntary organs (e.g., breathing, heartbeat, hormonal/circadian processes) make us remarkably adept at spotting rhythm when it shows up. Ancillary to this view is the notion that all of our senses are capable of experiencing a rhythm, as the processing of all sensory stimuli is necessarily serial and two sensory events (of the same modality) cannot occupy the same moment in time. This facilitates the grouping of like sensory experiences across time if they meet some requisite idea of similarity.

***Rhythmic Behavior in the Laboratory***

Much of the current work on acquired or produced rhythm is concerned with sensorimotor synchronization (e.g., the vast body of literature on bimanual tapping—see Repp, 2005, for a review). This work has been principally concerned with brief (<1 s.) production intervals and often focuses on idiosyncrasies in participants' phase patterning and corrections in limb movements. Furthermore, the experimental paradigms employed in the majority of sensorimotor synchronization research is of a very basic and artificial nature; participants are typically aware that they are going to produce a rhythm, so any rhythmic behavior observed is never a by-product of a naturally occurring temporal marker in the environment. As the rhythmic elements of interest for rhythmic operation in real-world tasks are of a more cognitive and less of a sensorimotor nature, much of the tapping literature will be bypassed here in favor of work that describes rhythm as a cognitive phenomenon. The prodigious body of duration estimation research will be similarly pared down to include only research that describes the extent to which knowledge of time draws from attentional resources or increases cognitive strain. Research in this domain generally follows one of two paradigms: (1) the *prospective* duration estimation paradigm, in which participants are told ahead of time that they will be estimating duration, and (2) the *retrospective* paradigm, in which participants are asked to estimate the duration of a task after it has been performed. The majority of this research shares the problem of artificiality with the sensorimotor synchronization literature; participants are performing an abstract task in a laboratory setting, and many times the temporal importance of the task is made explicit ahead of time. Another important difference between duration estimation in the laboratory and temporal awareness in real world control settings is that participants are often asked to respond with numerically labeled durations, which can be practiced subvocally throughout the task. In real world settings, numerically labeled durations for the temporal relationships between task elements are seldom explicitly processed in vocal or subvocal fashion.

Avni-Babad and Ritov (2003) found that highly regular presentation of high priority events (HPEs) in what subjects thought was a memory task led to shorter duration estimations than variable HPE conditions. The authors hypothesized that the routine presentation allowed subjects to stop experiencing HPEs as contextual changes that could be counted and recalled, and required minimal cognitive resources to be deeply encoded. In short, attentional resources ceased being necessary for effective task completion. These findings held across a variety of conditions and in two quasi-experimental survey studies of vacationers and factory workers (Avnie-Babad & Ritov, 2003).

Carlson and Cassenti (2004) uncovered several advantages offered by rhythm in the effortful and error-prone activity of event counting. Counting subvocally can be a naturally rhythmic process, particularly when used as a duration estimation technique (Carlson & Cassenti, 2004). It was found that the counting of events that occurred at a precise presentation schedule (i.e., rhythmically) was more accurate than if the events had variable display rates. Through the course of six experiments, three of which included rhythmic presentation as an independent variable, it was ascertained that end counts of rhythmically displayed events were as accurate as self-paced conditions, although error monitoring was weaker in the rhythm condition. In subsequent experiments, force-paced rhythmic presentation proved as accurate as varied presentation with a much slower average time per step. Taken as a whole, the counting of events that were rhythmically presented was more accurate, with participants tending toward greater ignorance of their error rates than in the variable presentation groups (according to self-report confidence ratings). Additionally, errors in the counting of rhythmic events tended to be of the undercount variety, and errors in the counting of variable presentation events were typically overcounts. Carlson and Cassenti believe that rhythmic presentation of stimuli tends to lessen the strain on executive processes by streamlining the processing of intentions. So long as presentation remains fluent, no goal representation of lower-level intentions must be maintained in working memory. However, implicit in this process is poor error awareness, as error monitoring in force-paced rhythmic counting is typically reserved for detection of flow disruption.

Grosjean, Rosenbaum and Elsinger (2001) examined the importance of display interval constancy in instances when timely and accurate decisions are needed. By manipulating stimulus presentation on the critical trial of a forced-choice decision-making task so that the final presentation appeared either earlier or later than expected relative to past trials, Grosjean et al. found that subjects exhibited much longer reaction times and greater accuracy on the early presentation trials. This was explained in terms of a modified diffusion model, which states that subjects begin sampling the perceptual display prematurely based on an adjustable criterion often mediated by performance on previous trials. If sampling starts too early, the variability (and thus error rate) of potential responses increases, and reaction time is decreased. Early presentation of a stimulus means that a decision threshold has yet to be reached, and decisions can be made based on the careful deliberation of veridical information. By contrast, a later than expected stimulus presentation will lead to fast but less accurate decisions, as a decision threshold has likely been reached prematurely at this point. Grosjean et al. submit that time-influenced anticipation holds not only for low-level reaction time tasks, but also for higher level, choice-oriented scenarios. To maximize consideration of choices and avoid temporally-influenced anticipation, Grosjean et al. recommend that temporal uncertainty should be increased and accuracy stressed over speed.

The findings of Krampe, Mayr and Kliegl (2005) offer additional support for a skill-based version of temporal awareness. Building on Vorberg and Wing's (1996) *rhythm program hypothesis*, which states that produced rhythm is mediated by a series of timekeepers programmed along certain sequencing parameters, Krampe et al. (2005) sought to demonstrate a dissociation between high-level and low-level rhythm programs with their *executive control hypothesis of timing*. This hypothesis states that rhythm programs (similar to motor programs in that slight changes in parameters can be effected without making the program obsolete) can be created as mental sets outlining attributes such as the number and sequencing of behaviors (e.g., tapping motions), and that these on their own to not demand executive resources to operate (Krampe et al., 2005). A program created for tapping a simple span of quarter notes at a continuous tempo with one hand, for example, requires little or no executive resources unless an additional program is created for the other hand to tap a syncopated rhythm against that rhythm; at this point manipulation of the hopefully complementary sets becomes akin to a switching task—a well-documented paradigm for exhibiting executive strain (Krampe et al., 2005). To further complicate this procedure, one can require increasingly complex polyrhythms (e.g., Pressing, Summers & Magill, 1996; Jones, Jagacinski, Yee, Floyd & Klapp, 1995) to demonstrate the effects of multiple competing programs in distinct time signatures, which is a task few non-musicians can conceive, let alone accomplish. Krampe et al. (2005) indeed demonstrated experimentally that low-level timing tasks exhibited a much lower mean-variance signature in both young and older adults than in executive-control conditions. This finding is consistent with earlier work by Krampe, Engbert and Kliegl (2001) that showed that older adults performed equally well as younger adults in isochronous tapping tasks, but less well in increasingly complex tasks with competing motor-programs. It has yet to be verified experimentally whether rhythmic operation of complex tasks in naturalistic settings is a low-level rhythm task or an executive control task. However, the findings of Kliegl et al. (2005) are consistent with Okada (1992), which appears to meet the criterion (uni-manual on-off alternations of a given time and sequence) for a low-level task.

Additional evidence from the rhythm literature takes the form of unintentional entrainment of limb movements to visual or audio environmental cues. A study by Schmidt, Richardson, Arsenault and Galantucci (2007) found that presenting participants with a rhythmically oscillating visual stimulus (a small square) while they swung a pendulum at their "comfort period" produced a predicted coupling of the two after prolonged exposure. This finding suggests that not only are limb movements coupled with the oculomotor system, but that this coupled system can become unintentionally entrained with environmental visual stimuli. In a second study focusing on intentional entrainment, participants were instructed to match the period of their pendulum movements with the oscillating square, and this led to stronger (i.e., more stable) entrainment. The key element for rhythmic operation is the *unintentional* aspect of rhythmic entrainment; that one does not have to *try* to achieve synchronicity in motor movements with environmental stimuli speaks to the fundamentally skill-based nature of rhythm.

***Cognitive Models of Time Perception***

Several cognitive models exist that can explain relevant aspects of human mental processes during rhythmic experiences. Zakay & Block's (1994) *attentional gate model* will be focused on here because it takes into account the complexities of attention-sharing experienced by humans during time estimation in dynamic resource-demanding tasks. An 'arousal center' in the model is responsible for calibrating the rate (measured in number of pulses per temporal unit) of the counting units. Temporal meaning or importance causes the attentional gate to open wider, thus allowing more pulses to pass through. A proposed "switch," which opens or closes a cognitive counter in an all or none fashion, is turned on when perception of time becomes important, and the cognitive counter is set to zero. When a relevant time period ends, output from the cognitive counter is sent to working memory, as well as reference memory and a cognitive comparison mechanism. Outputs from all of these are then compiled and sent to a response mechanism (Zakay & Block, 1994). This model posits that temporal relevance (the degree to which time seems important to the individual) and temporal uncertainty (the degree to which duration seems unpredictable), determine to a large part when the proposed attentional gate opens and the switch to a cognitive counter sets to the 'on' position. In brief, knowledge that time will be important turns on a switch (an all or none occurrence), and the counter, set at zero, begins accumulating pulses at a rate determined by the "width" of the attentional gate. An environmental cue signaling the end of a time-relevant task causes the switch to turn off the counter, and the information regarding the number of pulses in the counter is sent to the various decision mechanisms. While it is assumed that temporal relevance would be important in most time-sensitive supervisory tasks to some degree, it is temporal uncertainty that is particularly affected by rhythmic properties.

### *Brain Bases of Cognitive Rhythm*

Ivry (1996), in a concise review of possible brain bases for rhythmic understanding, offered additional support for rhythm as a primarily low-level function. Patients with damage to their cerebellum have difficulty with perceptual tasks that require precise timing, and exhibit increased variability on finger-tapping tasks relative to normal patients. Additionally, subjects with impaired functioning of their basal ganglia, such as Parkinson's and Huntington's sufferers, were similarly impaired on tapping tasks. Though damage to higher-level cortical structures has been shown to impair perceived timing under certain conditions, there is no correlation between cortical damage and rhythm discrimination (Ivry, 1996). While measures of timing performance of the basal ganglia and cerebellum are usually conducted in a different fashion, with >1 second intervals comprising much of the research on lesioned basal ganglia patients, and <1 second intervals for lesioned cerebellar patients, it is evident that as a system the mid-and low-level structures, respectively, play an important role in rhythm perception. Although simplistic, the correlational finding that high-level cortical structures, traditionally seen as necessary for high-level cognitive functions such as executive control, appear to have little to do with rhythm perception, and mid- to low-level structures apparently do, lends support to the concept of rhythm as skill-based temporal awareness.

### *Rhythmic Behavior in Naturalistic Settings*

Apart from Okada (1992), there are few instances of rhythmic operation in naturalistic settings, attesting to an overall dearth in the understanding of rhythmic control in the real world. Censullo, Lester and Hoffman (1985) found that mothers utilize rhythmic cues when interacting with their newborns. As mother and child lack an effective means of communication in the early stages of child-rearing, it becomes necessary to use temporal landmarks, such as when the child was last fed, in order to provide nourishment and interaction. A spectral analysis was performed on videotape of mother child interaction, and a clear rhythmic pattern in feeding times, playful interactions, etc., was revealed (Censullo et al., 1985). Although a clearly different situation than the rhythmic control of a nuclear power plant or airplane cockpit, it makes sense on a heuristic level than a mother would reduce workload by noticing rhythmic cues rather than guessing the child's needs.

Another instance of rhythm being used to reduce cognitive load can be found in Braem's (1999) study on the temporal patterns of late versus early Swiss German sign language speakers. The researchers, themselves deaf, noticed that the early sign-learners had trouble understanding the signs of the later learners because their movements were less rhythmic. It could be that the fluent flow of syntax reduces workload, much in the same way observed in Carlson and Casseni (2004). A lack of rhythmic flow leads observers/listeners to constantly maintain potential intentions on the part of the presenter in their working memory.

### ***Premises, Thesis, and Hypotheses***

The purpose of this research was to examine the conditions under which rhythmic behavior can be acquired, the types of errors that may be expected in rhythmic behavior, and the effects of rhythm on task performance and mental workload in an abstract time-sharing task. As TA in non-dynamic or 'rhythmic' environments does not appear to require the high-level cognitive resources associated with TA in dynamic environments, controlled processes that afford rhythmic presentation of task elements may benefit from further study of rhythmic control. The review of relevant literature above may be summarized in four specific premises:

*Premise 1*. Rhythm as a cognitive construct is a low-level phenomenon associated with mid- and low-level brain structures that does not draw from the high-level cognitive resources associated with decision-making, mental simulation, knowledge-based problem solving, etc (Ivry, 1996; Krampe, Mayr and Kliegl, 2005; Rasmussen, 1983; Reason, 1990).

*Premise 2.* Rhythm can become entrained without conscious thought after prolonged exposure to the rhythmic stimulus (Schmidt, Richardson, Aresenault and Galantucci, 2007).

*Premise 3*. The low-temporal uncertainty associated with rhythmic environments makes available attentional resources for non-temporal secondary tasks in a time-sharing experimental paradigm (Zakay & Block, 1994; Zakay, Block & Tsal, 1996).

*Premise 4*. Observable rhythmic behavior is schema-driven, automatic and skill-based (Krampe, Mayr and Kliegl, 2005; Vorberg & Wing, 1996; Wickens & Holland, 2000), and thus subject to the attentional slips described by Reason (1990) rather than high-level mistakes.

*Thesis*. The basic thesis of this research may therefore be stated as follows: Rhythmicity will be entrained in any task exhibiting regularity over time; furthermore, rhythmic performance will have specific advantages in dual- or multi-task setting as it frees cognitive resources from temporal task demands to other demands improving overall performance. However, rhythmic behavior also incurs cost in terms of disposing performers towards specific temporal errors.

Specifically, the following hypotheses were tested:

*Hypothesis 1:* Rhythmicity in operator behavior will be acquired over time and without conscious attention. Several metrics (to be described in a later section) were developed to track the timing of certain participant actions, and it was predicted that in rhythmic conditions a) the interval times between these discrete behaviors would become regular over time, and b) that participants would exhibit more timeliness in their responses.

*Hypothesis 2:* In rhythmic conditions—and the performance indeed is rhythmic—participants will have more attentional resources available for the performance of secondary tasks—even those known to exhibit bi-directional interference with duration estimation, such as mental math (Brown, 1997) resulting in better secondary task performance than in the arrhythmic condition. An interaction between task difficulty and rhythmicity will lead to especially poor performance in conditions pairing arrhythmic presentation of tasks with high task difficulty.

*Hypothesis 3:* If the participants entrain into rhythm, they will be vulnerable to temporal errors should the rhythm of the task change.

*Hypothesis 4*: The participants will experience less subjective mental workload in rhythmic conditions than in arrhythmic conditions.

# Chapter 2: Method

## *Participants*

Participants were recruited from the population of undergraduate students at RIT. Fliers were posted around salient areas of the campus and course credit offered to students taking an undergraduate research methods class. Altogether 40 participants volunteered for the experiment, 20 males and 20 females, with a mean age of 21.6 years ($s$=4.96). Informed consent was acquired from all participants prior to the experiment.

## *Apparatus*

All participants completed the experiment on Dell Optiplex GX260 computers, with an Intel Pentium 4 CPU, 2.8 GHz, running Windows XP Professional 2002 SP2. The displays were Dell UltraSharp 15-in. LCD displays, with a resolution of 1280 x 1024 pixels. A standard keyboard and mouse were used to complete the response task and select the experimental trials.

## *Experimental Task*

The experimental program used in this study was modified from a computer program used by Levinthal and Rantanen (2004) and Rantanen and Levinthal (2005). The program presented participants with an abstract time-sharing task. A computer screen was divided into four quadrants, of which only one was visible at a time. To view other quadrants, participants were required to move a cursor (using a mouse) to the desired quadrant. The previous quadrant on the screen would become blank, and the desired quadrant would become visible. Each quadrant contained a red progress bar, a mark on the bar indicating the window of opportunity to reset the timer (the response task), and instructions for resetting the timer (either an arbitrary 2-digit code, or a mental arithmetic problem). See Figure 1 for a screenshot of the experimental display.

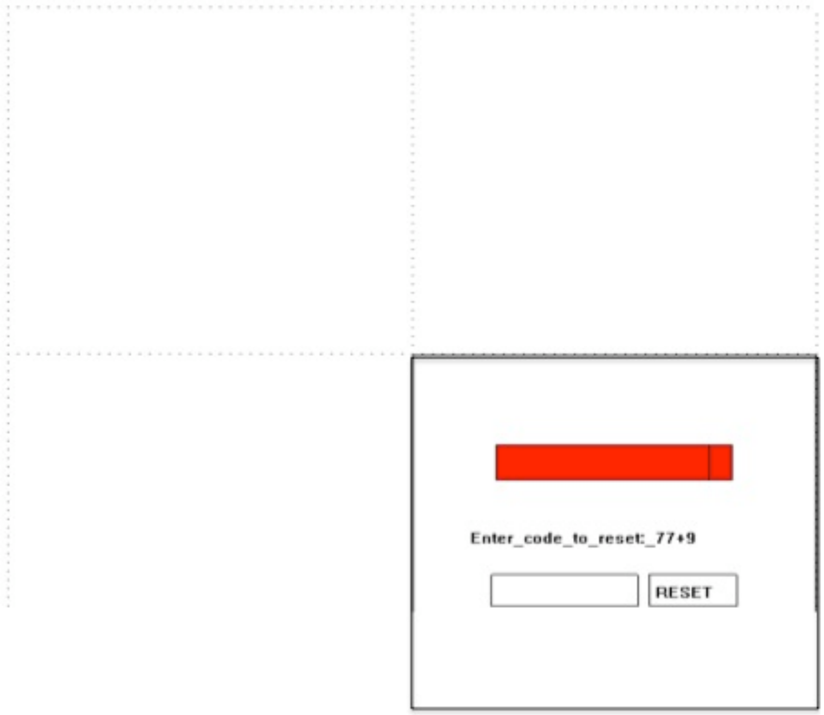


*Figure 1*. Screen capture from the computer program used in the experiment. Only one quadrant was visible to the participants at a time, but the timers were running simultaneously in all quadrants, also those that were masked. The participants' task was to reset the timers before they filled out by entering a code and pressing the 'Enter' key on a keyboard.

Participants were thus responsible for two different kinds of tasks during each block of experimental trials. The temporal task required them to keep track of and reset each of the four timers within their unique windows of opportunity (WO). A second, nontemporal task, required performing simple mental arithmetic or rote copying a code to reset the timers. Any time that participants used their cursor to select another task by mousing over the pane of their choice, a 'task-change' was recorded in the data file. A 0.5-second delay between the time the cursor entered the pane and the display of pane contents prevented participants from adopting the strategy of constant cursor activation by rapidly moving in a circle around the panes. After the progress bar reached a thin black line, the WO opened which allowed for the performance of the response task using the keyboard; successful typing of the required code and pressing the 'Enter' key reset the progress bar, after which the timer started anew.

***Independent Variables***

There were two independent variables in this experiment: (1) rhythmicity, and (2) response task difficulty. Rhythmicity was defined as the extent to which highly regular response intervals could be utilized to successfully perform the four tasks. Three levels of rhythmicity and two levels of response task difficulty were implemented.

*Rhythm.* In the easy rhythm condition all progress bars took 20 seconds to move from 0 to 100%, and the WO opened when the bar reached the 50% mark, or 10 s after they were reset. In other words, the task could be successfully performed by resetting a progress bar every 10 s. A clear clockwise or counter-clockwise movement through the panes sufficed for the pattern of task selection and responding. Response task execution in this condition could be very regular and is determined by the pattern of interaction that the participant initially employed (i.e., replication of the original sequence of progress bar resetting).

In the difficult rhythm pattern, three of the four tasks were consistent in progress bar speed and WO percentage, with a fourth pane differing on both of these dimensions. The three similar tasks progressed from 0 to 100% in 20 seconds with the WO at 50%, while the fourth task moved from 0 to 100% in 40 seconds, with the window of opportunity opening at 90%. A successful strategy in the difficult rhythm conditions entailed developing a rhythm for the three like tasks, and a separate rhythm for the progress of the fourth.

In the arrythmic condition the progress bar speeds and WO were determined quasi-randomly, at a pace that was determined by the author to allow for reasonably successful mathematical computation, but so that no regular patterns of timer-checking and resetting could be established.

*Response task difficulty*. The two levels of response task difficulty were meant to assess the subject's ability to carry out both low- and high-level tasks while keeping track of the temporal component of the task. If rhythm is indeed a low-level, schema-driven phenomenon then one can expect a surplus of the attentional capacities necessary to perform high-level response tasks in light of the low temporal uncertainty (Zakay & Block, 1996).

The low difficulty conditions involved typing of an arbitrary 2-digit number code on the keyboard. These numbers were selected randomly; pairs requiring the typing of the same number twice (e.g., 88) were discarded in favor of heterogeneous pairs.

In the high difficulty conditions the participants had to perform simple mental math task for the timer resetting code. Mental arithmetic has been established as a high-level, executive-heavy task that exhibits bi-directional interference with time perception (Brown, 1997). Pilot data revealed that the problem space associated with 2-digit numbers added to 2-digits numbers was too large a strain on working memory to consistently execute successfully under time pressure, so it was determined that a 1-digit number added to a 2-digit number was more appropriate. Problems were selected in a pseudo-random fashion which assured that the addition of the two addends always required a carry operation (ex. 47+6=53) to avoid the useful but too resource-conserving heuristic of ignoring the addend in the first position of the larger number, thus creating a single-digit problem (ex. 42+5=47) (Adams & Hitch, 1997).

### *Dependent Variables*

The experimental program recorded and time-stamped to millisecond accuracy all events during experimental runs. From these data, the following dependent variables were derived:

*Time to first action*. Time to first action (TFA) was calculated by subtracting the time of a window of opportunity (WO) opening from the time of the first keystroke of the responding action. The total number of TFA calculations was determined by the number of trials completed by the participant in the block; a number influenced by individual differences in mental arithmetic capabilities or personal control "style".

*Dwell before action*. Dwell before action (DBA) was calculated by subtracting the time that the participant first entered the pane for a given task from the time of the first keystroke of the response action.

*Dwell before task change.* Dwell before task-change (DBT) provided an indication of how long participants chose to remain on a completed task and observe the progress of the newly started timer before moving on. This was calculated by subtracting the time that the participant completed (reset) a response task from the time of the task-change.

*Moving variance of task changes*. Moving variance (MV) was calculated by subtracting the time of a task-change and all subsequent task-changes from one another, providing an indication of the regularity with which participants were completing and selecting new tasks. After all the differences for a given block of trials were calculated, these values were placed into chronological groups of five, and the standard deviation is calculated for these groups. This provided a sense of participants' task selection/pane visitation schedule over time.

In addition to the above measures of temporal awareness and rhythmicity, overall task performance, subjective workload, and subjective perceptions of the temporal characteristics of the experimental task were measured:

*Performance.* The performance measures examined were the accuracy of responses at both levels of task difficulty. After a participant entered their arbitrary code or mental arithmetic sum, they hit the 'return key' to reset the task. If the answer for the response task was incorrect at the time the return key was hit, a zero was recorded in the data file and they had to try again. The ratio of zero values to ones comprised the performance score.

*Workload.* Subjective mental workload was taken using a modified version of the NASA-TLX (Hart & Staveland, 1988). Participants were asked to rate workload on five of the six dimensions commonly measured by the NASA-TLX: 1) mental demand, 2) temporal demand, 3) own performance, 4) effort, and 5) frustration (see Appendix K). The "physical demand" dimension was dropped from the forms under the assumption that the light physical nature of the task would lead to largely inconsequential ratings of this component. All of the loading factors were rated on a scale of 0 (this factor did not contribute to workload) to 100 (the factor greatly contributed to workload).

*Post-experiment questionnaire.* Participants were asked four questions concerning the perceived rhythmicity of the environment and the difficulty of the various conditions.

***Design***

A within-subjects, full factorial 3 (rhythmicity: easy, difficult, arrhythmic) X 2 (response task: easy, difficult) design was employed to assess the differences in rhythmic behavior under all possible combinations of secondary task difficulty and rhythmicity. The specific pairing of rhythmicity and response task difficulty comprised the six conditions that participants were exposed to, and condition order was randomized for all participants. A trial was defined as resetting one timer; therefore, with four simultaneous timers that restarted after reset, an experimental block of 5 minutes consisted of 14.12 trials on the average. The exact number of trials depended on individual participants' performance. In addition, in conditions that contained an *easy* or *difficult* rhythmic presentation of stimuli, there was one "trick" played on participants to interrupt their rhythm. This consisted of altering the speed of the trial from 20 seconds (progress bar moves from start to finish) to 10 seconds, doubling its speed; this always occurred in the $12^{th}$ overall trial (the $3^{rd}$ trial of the quadrant in which the trick occurred), but in a different pane for each of the rhythmic conditions. Data from these trials were analyzed separately from the regular trials.

### *Procedure*

Participants were told that the experiment was designed to look at mental workload during multi-tasking; no mention of rhythm was made. After the NASA-TLX forms and definitions were explained, all participants completed two 2-minute practice blocks designed to familiarize them with the equipment and the experimental task. There was one practice trial each for the two levels of response task difficulty, and the progress bar speeds were randomized. Participants were allowed to repeat the practice trial in the event they did not feel comfortable with the task. After completing the training, the participants were instructed to rank the NASA-TLX workload components as they pertained to the experimental task.

All participants completed six 5-minute blocks of trials in a randomized order. Immediately following a block of trials, participants were asked to rate workload using a paper and pencil NASA-TLX form. Following the NASA-TLX ratings, participants were offered a break period and provided with refreshments before starting the next block of trials. In total, the experimental session lasted approximately 1 hour per participant.

# Chapter 3: Results

## ***Preliminary Analyses***

*Distributions of data.* Data were examined in dotplots (see Appendix A) for the dependent measures TFA, DBA and DBT across five 1 minute 'epochs' of interaction. I broke the experimental block into 1-minute epochs because it was hypothesized that regularity and timeliness of discrete actions would increase over time in the rhythmic conditions. Analyzing the data by epochs afforded a more evolutionary view of timed behaviors than procedures, which look only at main and interaction effects of the manipulations on the conditions as a whole. The majority of responses (typing the required code to reset the timers) within the windows of opportunity were quite rapid for TFA and there were relatively few high (late) values; means for TFA therefore exhibited a pronounced positive skew. A log base 10 transformation was applied to these data in order to normalize them for the performance of inferential statistics, as ANOVAs assume normally distributed data (Field, 2005).

*Outliers.* The mean TFA, DBA and DBT scores were converted to Z-scores and examined for outliers. Any value over 3.5 standard deviations from the mean was deemed an outlier and replaced with the next highest value not considered an outlier. This reduced the impact of these outliers while also ensuring that the replacement scores remained near the end of the range in a given subset of data (Tabachnik & Fidell, 1989). This resulted in the removal of 23 values in total: 2 outliers in the difficult rhythm, easy RT condition; 7 in the easy rhythm, difficult RT condition; 4 in the difficult rhythm, difficult RT condition; 6 in the arrhythmic, easy RT condition; and 4 in the arrhythmic, difficult RT condition. As there were 3600 total data points for these measures, the removal of the 23 values amounted to 0.006% of the values.

*Epoch vs. overall analyses.* The means for all temporal awareness measures (i.e., TFA, DBA, and DBT, Moving Variance) were calculated by epoch, epoch aggregate (pre- and post-trick epochs), and by condition as a whole (see table 1); 2 (easy RT, difficult RT) X 3 (easy rhythm, difficult rhythm, arrhythmic) ANOVAs were performed on the epoch aggregates and overall to show the effects of rhythm, response task, and any interactions between the two on these measures. As the trick manipulation only led to significant differences between the pre- and post-trick aggregates for one of the measures (DBA in the arrhythmic, easy response task condition), only results from the 2 X 3 ANOVAs performed on all epochs combined will be discussed here (see Appendix J for summary results from these ANOVAs). One-way ANOVAs were then used to analyze across epochs in the same condition and between epochs in different conditions to see the effects of time on the condition manipulations. Calculation of 95% confidence intervals allowed for comparison of means between epochs in a given condition, and between conditions in a given epoch. The American Psychological Association (2001) and others (Loftus, 1996; Wickens, 1998) recommend using confidence intervals to describe differences in means because they circumvent the loss of power observed in null-hypothesis significance testing, and can be used to infer effect sizes directly.

### *Time to First Action*

TFA scores were calculated by subtracting the time of the first keystroke of the response action from the time that a WO opened. Mean TFA was calculated for each of the five epochs and then an overall TFA was calculated by averaging the means from all five epochs. It was expected that participants would be able to predict the time of a WO opening more accurately in rhythmic conditions, and thus exhibit increased timeliness in their response tasks as compared to the arrhythmic conditions.

*Overall TFA.* I performed a 2 X 3 ANOVA to evaluate the effects of rhythm and response task difficulty on TFA scores that had undergone a log base 10 transform. (All figures and subsequent discussion effects from this point on will refer to raw TFA values in seconds.) This analysis revealed a significant main effect for response task $F(1,238) = 147.25$, $p < .05$. In the difficult RT conditions ($M = 5.3$, $SD = 5.11$, $CI_{95} = [3.72, 6.88]$), which involved mental arithmetic to solve for the timer resetting code, the participants were on the average 3.37s slower to reset than in the easy RT conditions ($M = 1.92$, $SD = 1.58$, $CI_{95} = [1.43, 2.41]$), where they only had to copy the code to reset the timer. There was no significant effect for rhythm $F(2,238) = 1.22$, $p > .05$; however, there was a significant interaction effect between rhythm and response task $F(2,238) = 7.5$, $p < .05$, indicating that the effects of response task difficulty were more pronounced under certain rhythm levels. Looking at Figure 2, it is revealed that participants' TFA scores are similar for both levels of response task difficulty in the arrhythmic conditions, but there is a tendency towards slower TFA scores in the difficult response task conditions as rhythm increases. This difference is most pronounced between the easy rhythm, easy RT condition, ($M = 1.67$, $SD = .85$, $CI_{95} = [1.41, 1.93]$), and the easy rhythm, difficult RT condition ($M = 6.53$, $SD = 6.12$, $CI_{95} = [4.63, 8.43]$), with a discrepancy of 4.86 s on average. This suggests that rhythm actually serves to slow down the first action of a response task subsequent to a WO opening for difficult RTs.

Table 1

*Means (in seconds), standard deviations, and 95% confidence intervals calculated for the timing measures (TFA, DBA, DBT, Moving Variance) by epoch, epoch aggregate, and all epochs combined (in rows). Conditions are depicted in columns. Confidence interval data from this table was used to determine whether the differences between the epoch aggregates were significantly different from one another at the .05 alpha level.*

| Timing measure | | Easy rhythm, easy RT | | | Difficult rhythm, easy RT | | | Easy rhythm, difficult RT | | | Difficult rhythm, difficult RT | | | Arrhythmic, easy RT | | | Arrhythmic, high-level response | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *M* | *sd* | $CI_{95}$ | *M* | *sd* | $CI_{95}$ | *M* | *sd* | $CI_{95}$ | *M* | *sd* | $CI_{95}$ | *M* | *sd* | $CI_{95}$ | *M* | *sd* | $CI_{95}$ |
| Time to first action (TFA) | Epoch 1 - 3 | 1.79 | 0.83 | 0.26 | 1.7 | 0.77 | 0.24 | 6.27 | 6.36 | 1.97 | 5.52 | 5.33 | 1.65 | 2.55 | 3.81 | 1.18 | 3.97 | 4.13 | 1.28 |
| | Epoch 4 & 5 | 1.53 | 1 | 0.31 | 1.73 | 0.75 | 0.23 | 6.92 | 6.07 | 1.88 | 5.15 | 5.35 | 1.66 | 2.22 | 2.64 | 0.82 | 4.1 | 4 | 1.24 |
| | All Epochs | 1.67 | 0.85 | 0.26 | 1.71 | 0.7 | 0.22 | 6.53 | 6.12 | 1.90 | 5.37 | 5.25 | 1.63 | 2.4 | 3.21 | 0.99 | 4.01 | 3.97 | 1.23 |
| | | | | | | | | | | | | | | | | | | | |
| Dwell before action (DBA) | Epoch 1 - 3 | 1.77 | 0.4 | 0.12 | 2.02 | 0.5 | 0.15 | 2.81 | 0.82 | 0.25 | 3.28 | 1.12 | 0.35 | 1.96 | 0.47 | 0.15 | 3.6 | 1.35 | 0.42 |
| | Epoch 4 & 5 | 1.75 | 0.44 | 0.14 | 2.05 | 0.62 | 0.19 | 2.92 | 0.89 | 0.28 | 3.23 | 0.95 | 0.29 | 1.71 | 0.38 | 0.12 | 3.34 | 1 | 0.31 |
| | All Epochs | 1.76 | 0.41 | 0.13 | 2.04 | 0.5 | 0.15 | 2.85 | 0.82 | 0.25 | 3.26 | 1.03 | 0.32 | 1.85 | 0.41 | 0.13 | 3.5 | 1.13 | 0.35 |
| | | | | | | | | | | | | | | | | | | | |
| Dwell before task-change (DBT) | Epoch 1 - 3 | 0.92 | 0.15 | 0.05 | 0.95 | 0.15 | 0.05 | 1.02 | 0.19 | 0.06 | 1.07 | 0.22 | 0.07 | 0.9 | 0.14 | 0.04 | 1.07 | 0.22 | 0.07 |
| | Epoch 4 & 5 | 0.92 | 0.16 | 0.05 | 0.95 | 0.15 | 0.05 | 1 | 0.21 | 0.07 | 1.04 | 0.17 | 0.05 | 0.9 | 0.14 | 0.04 | 1.05 | 0.26 | 0.08 |
| | All Epochs | 0.92 | 0.15 | 0.05 | 0.94 | 0.14 | 0.04 | 1.01 | 0.19 | 0.06 | 1.06 | 0.18 | 0.06 | 0.9 | 0.14 | 0.04 | 1.05 | 0.22 | 0.07 |
| | | | | | | | | | | | | | | | | | | | |
| Moving Variance | Epoch 1 - 3 | 0.97 | 0.67 | 0.21 | 1.09 | 0.7 | 0.22 | 1.3 | 0.81 | 0.25 | 1.72 | 0.79 | 0.24 | 0.93 | 0.38 | 0.12 | 1.61 | 0.84 | 0.26 |
| | Epoch 4 & 5 | 1.28 | 0.95 | 0.29 | 1.62 | 1.2 | 0.37 | 2.04 | 1.68 | 0.52 | 2.44 | 1.55 | 0.48 | 1.16 | 0.33 | 0.10 | 2.23 | 0.99 | 0.31 |
| | All Epochs | 1.28 | 0.9 | 0.28 | 1.5 | 0.95 | 0.29 | 1.88 | 1.12 | 0.35 | 2.33 | 1.1 | 0.34 | 1.21 | 0.39 | 0.12 | 2.21 | 0.94 | 0.29 |

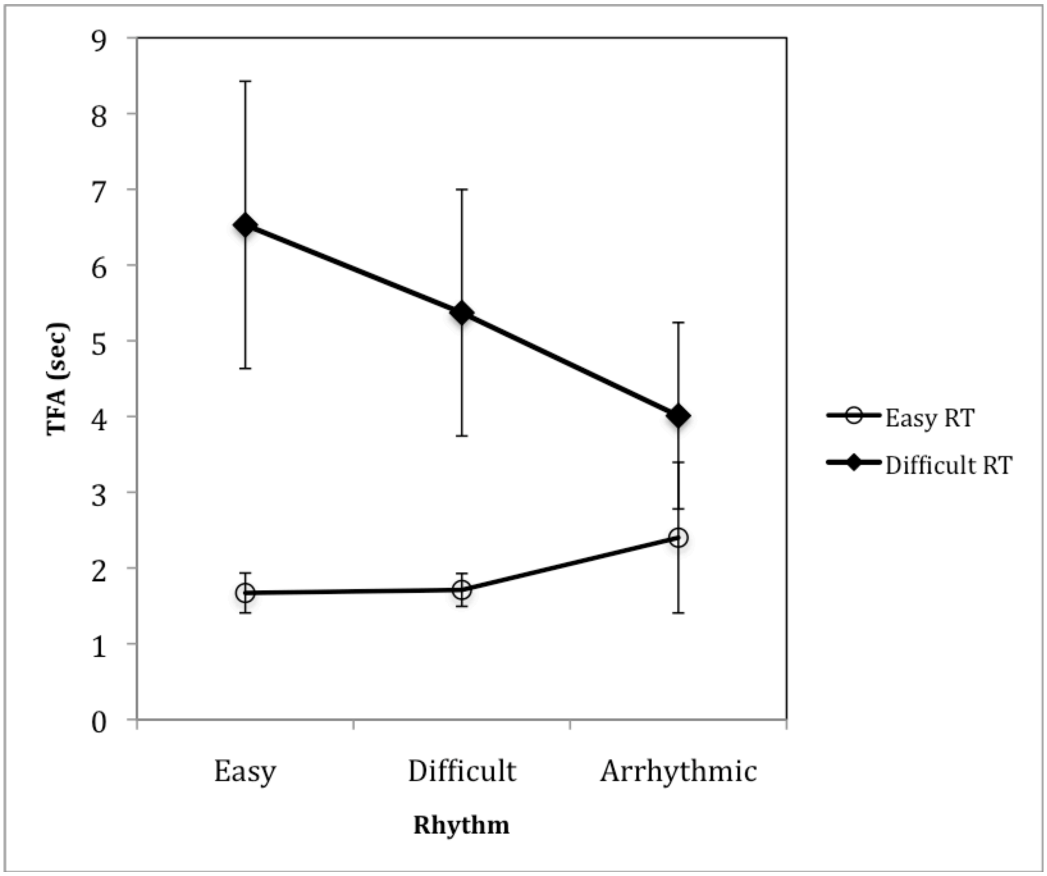


*Figure 2.* Mean TFA for both low- and high-level response tasks (RTs) across all three levels of rhythm. Bars depict 95% confidence intervals.

***Dwell Before Action***

DBA scores were tabulated by subtracting the time of a task-change from the time of the first keystroke of the response action in the new pane. Participants were expected to exhibit larger DBA scores in rhythmic conditions, as it was thought they would be able to anticipate WO times more accurately and hence arrive at their next task (pane) earlier, or with some time before the opening of the WO on the particular task.

The 2 X 3 ANOVA revealed main effects for both response task $F(1,238) = 188.52$, $p < .05$, and rhythm $F(2,238) = 6.32$, $p < .01$, with participants exhibiting 1.32 s slower DBA times in the difficult RT conditions ($M = 3.2$, $SD = .99$, $CI_{95} = [2.89, 5.51]$) as compared to the easy RT ($M = 1.88$, $SD = .44$, $CI_{95} = [1.74,1.92]$) conditions, and a non-significant trend toward increased toward increased DBA times in difficult rhythm/arrhythmic conditions. There was no interaction between the two factors $F(2,238) = 2.94$, $p = .055$. As depicted in Figure 3, dwell time on a task before opening of its WO increased as rhythm decreased in difficult response task conditions. Counter to the hypothesis, scores in the easy rhythm, difficult response task condition ($M = 2.85$, $SD = .82$ , $CI_{95} = [2.60, 3.10]$) were significantly smaller than in the arrhythmic, difficult response task condition ($M$ = 3.5, $SD$ = 1.13 , $CI_{95}$ = [3.15, 3.85]), which suggests that in arrhythmic conditions participants tended to dwell on tasks prior to WO openings longer than in rhythmic conditions.

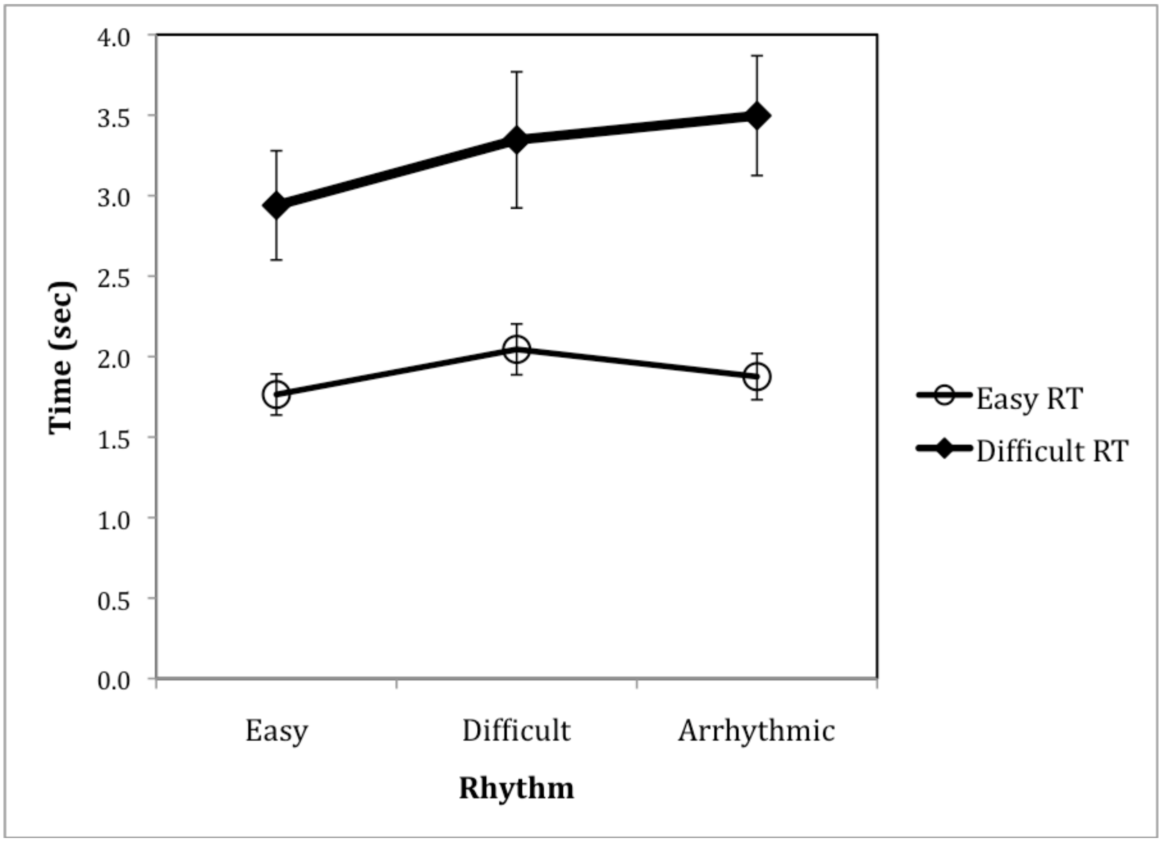


*Figure 3.* Mean DBA for both low- and high-level response tasks (RTs) across all three levels of rhythm. Bars depict 95% confidence intervals.

***Dwell Before Task Change***

DBT was calculated by subtracting the time of a task change from the time at which the ‘reset’ button was clicked, providing an indication of how long it took participants to move onto another task upon completion of the present one and providing an indirect measure of how aware they were of other WO openings. Participants in rhythmic conditions were expected to exhibit shorter dwell times as compared to the arrhythmic conditions.

*Overall DBT.* The 2 X 3 mixed-model ANOVA again revealed a significant main effect of response task $F(1,238) = 32.40$, $p < .01$, with participants in difficult response task conditions ($M$ = 1.04, $SD$ = .2, $CI_{95}$ = [.98, 1.10]) exhibiting on average .12 s slower DBT times than easy RT conditions ($M$ = .92, $SD$ = .14, $CI_{95}$ = [.88, .96]). No other main or interaction effects were observed, indicating that in general, subjects switched to the next eligible trial at around the same rate regardless of rhythm.

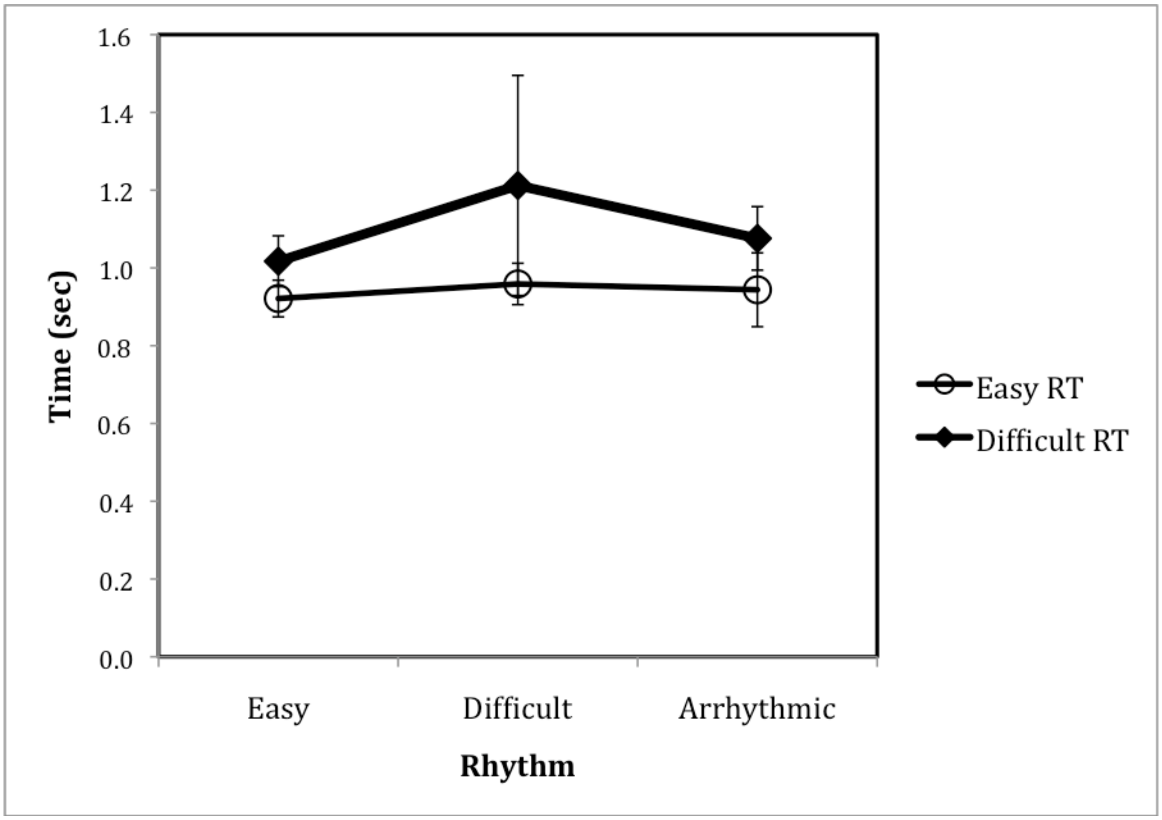


*Figure 3*. Mean DBT for both low- and high-level response tasks (RTs) across all three levels of rhythm. Bars depict 95% confidence intervals.

***Moving Variance of Task Changes***

While TFA, DBA and DBT comprised the primary temporal awareness measures, moving variance of task changes was examined to measure the acquisition of rhythmicity over time (i.e., regular switching between quadrants). To calculate moving variance, each task-change was subtracted from each subsequent task change, and the standard deviation was calculated for chronological groups of 5 of these values. A 2 X 3 mixed model ANOVA was performed to determine the effects of rhythm and response task on participants' moving variance. Variance in task selection behaviors was expected to be lower in rhythmic conditions as compared to arrhythmic conditions. Consistent with other dependent measures, there was a significant main effect for response task $F(1,224) = 32.57$, $p < .05$, with moving variance scores being .81 higher in difficult RT conditions ($M = 2.14$, $SD = 1.05$, $CI_{95} = [1.81, 2.47]$) as compared to easy RT conditions ($M = 1.33$, $SD = .75$, $CI_{95} = [1.10, 1.56]$) on the average. No main effect for rhythm was observed, nor any interaction between rhythm and response task (see Figure 4). Rhythm therefore demonstrated no discernible bearing on the regularity with which participants completed and subsequently selected their next task.

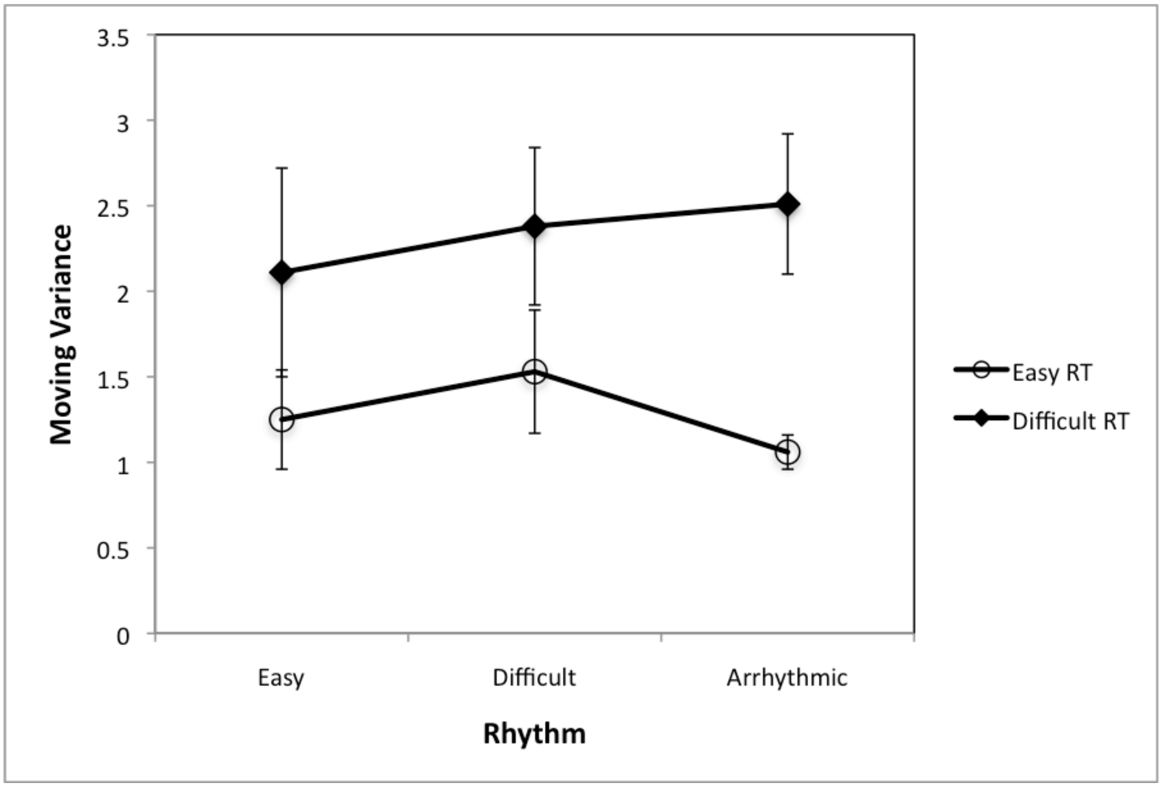


*Figure 4*. Mean moving variance of task change for easy and difficult response tasks (RTs) across all 3 rhythms. Bars depict 95% confidence intervals.

### ***Results by Condition and Epoch***

After reviewing the results of the 2 X 3 mixed-model ANOVAs, it was determined that in order to determine the effects of rhythm on temporal awareness and rhythmicity, the timing measures would have to be examined in time series, by epoch. As a result, mean TFA, DBA, DBT and moving variance of task change scores were calculated for each of 5 successive 1-minute epochs and plotted in line graphs. One-way ANOVAs were performed to describe the overall effects of condition and epoch (respectively) on the dependent measures and comparison of 95% confidence intervals was performed to describe which conditions and/or epochs were significantly different from one another. Confidence intervals were also used to infer significant differences visually (Figures 5-8) and determine effect sizes.

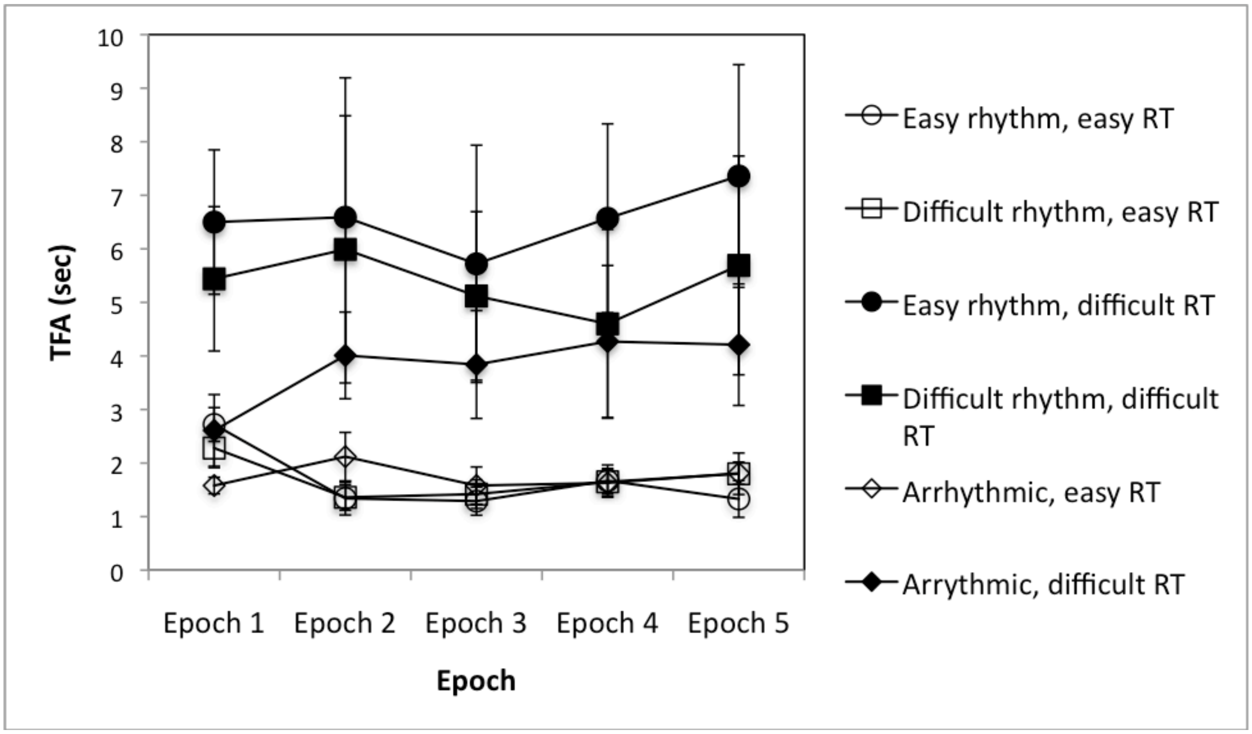


*Figure 5*. Mean TFA depicted across all 5 epochs of interaction for each of the 6 conditions. Conditions are represented as separate lines, and bars represent 95% confidence intervals. Difficult response task (mental arithmetic) conditions have filled-in symbols; note the separation between these and the easy response-task (empty symbol) conditions.

***TFA between conditions.***

Figure 5 represents TFA means with 95% confidence intervals for each of the conditions over 5 epochs. As rhythm was hypothesized to impact the timeliness with which participants performed the response task, participants were expected to exhibit lower TFA scores in the easy rhythm conditions than they were in difficult and arrhythmic conditions; difficult rhythm conditions were likewise expected to have lower TFA scores than the arrhythmic conditions. Furthermore, these differences were expected to develop as the block of trials progressed, and thus become more pronounced in the 2$^{nd}$ and 3$^{rd}$ epoch as compared to the 1$^{st}$ epoch. The 4$^{th}$ epoch, in which the trick manipulation occurred, was likely to see an increase in TFA scores for all rhythmic conditions, followed by a decrease in the 5$^{th}$ epoch as participants regained their TA.

What is instead seen in looking at Figure 5 is a pronounced effect of response task difficulty; there is clear separation between easy RT conditions (empty symbols, overall $M$ = 1.92, $SD$ = 1.58, $CI_{95}$ = [1.43, 2.41]) and difficult RT conditions (filled in symbols, overall $M$ = 5.3, $SD$ = 5.11, $CI_{95}$ = [3.72, 6.88]) across all epochs, with the difficult RT values being on average 3.37s slower than the easy RT. One-way ANOVAs performed on each of the 5 epochs to determine the effects of condition on transformed TFA means uncovered a significant impact of condition in each epoch; comparisons of 95% confidence intervals were used to unpack which conditions differed significantly from one another in a given epoch. This analysis revealed that it was indeed the difficult RT conditions that differed from the easy RT conditions, with the exception of epoch 1, in which the arrhythmic, difficult RT condition, $M = 2.61$, $SD = 2.16$, $CI_{95} = [1.94, 3.28]$) did not significantly differ from the easy RT conditions. Table 2 depicts the results from these one-ways ANOVAs, as well as untransformed values and their associated 95% confidence intervals. There was thus no support for the hypothesized trends in TFA.

***TFA by Epoch***

One-way ANOVAs and comparison of 95% confidence intervals were again used to examine means, this time by epoch within a given condition. As temporal awareness and perception of rhythm were expected to develop over time, it was hypothesized that TFA scores would decrease to steady-state with exposure to the experimental task in the rhythmic conditions but not for the arrhythmic conditions. The trick manipulation in epoch 4 was expected to drive TFA scores higher, followed by steady-state performance again in the 5$^{th}$ epoch.

Again turning to Figure 5, it is shown that the hypothesized drop in TFA with increased exposure occurred for the easy rhythm, RT condition, with a 1.38 s drop from the 1$^{st}$ ($M = 2.27$, $SD = 1.02$, $CI_{95} = [2.40, 3.04]$) to the 2$^{nd}$ epoch ($M = 1.34$, $SD = 1.00$, $CI_{95} = [1.03, 1.65]$), as well as for the difficult rhythm, easy RT condition, where a .92 s decrease was observed from the 1$^{st}$ ($M = 2.28$, $SD = 1.18$, $CI_{95} = [1.91, 2.65]$), to the 2$^{nd}$ epoch ($M = 1.36$, $SD = .78$, $CI_{95} = [1.12, 1.6]$). From here, steady-state performance was reached for both of these conditions, and was never broken. Significant differences between epochs in the other conditions were not observed at the .05 alpha level.

Table 2

*Summary table depicting the results from analyses of Time to First Action (TFA), in milliseconds. The experimental blocks were divided into five 60-second epochs, with the average number of trials in each epoch varying with the rhythmicity of the condition. The difference (Δ) column was calculated by subtracting the mean of the epoch from that in the previous epoch (e.g., E1-E2). Results from 1-way ANOVAs on epochs in each condition and on conditions in each epoch are provided, along with lower- and upper-bound 95% confidence intervals, which provide an indication of significance at the .05 alpha level. Note that Epoch 4 contained the 'trick' trial, which broke the rhythm in the rhythmic conditions.*

| | Epoch 1 | | Epoch 2 | | | Epoch 3 | | | Epoch 4 | | | Epoch 5 | | | 1-Way ANOVA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Condition | Mean (sec) | $CI_{95}$ [Lower, Upper] | Mean (sec) | Δ | $CI_{95}$ [Lower, Upper] | Mean (sec) | Δ | $CI_{95}$ [Lower, Upper] | Mean (sec) | Δ | $CI_{95}$ [Lower, Upper] | Mean (sec) | Δ | $CI_{95}$ [Lower, Upper] | *F* | p |
| 1. Easy Rhythm-Easy Response Task | 2.72 | [2.40, 3.04] | 1.34 | 1.38 | [1.03, 1.65] | 1.29 | 0.05 | [1.03, 1.55] | 1.67 | -0.38 | [1.38, 1.96] | 1.33 | 0.34 | [.99, 1.67] | F(4,197)=.343 | <.001 |
| 2. Difficult Rhythm-Easy Response Task | 2.28 | [1.91, 2.65] | 1.36 | 0.92 | [1.12, 1.60] | 1.67 | -0.31 | [1.15, 1.69] | 1.42 | 0.25 | [1.42, 1.88] | 1.65 | -0.2 | [1.41, 2.19] | F(4,190)=.848 | <.001 |
| 3. Easy Rhythm-Hard Response Task | 6.5 | [5.15, 7.85] | 6.59 | -0.09 | [3.99, 9.19] | 5.72 | 0.87 | [3.50, 7.94] | 6.57 | -0.85 | [4.81, 8.33] | 7.36 | -0.8 | [5.28, 9.44] | F(4,192)=1.121 | 0.059 |
| 4. Difficult Rhythm-Hard Response Task | 5.44 | [4.09, 6.79] | 5.99 | -0.55 | [3.50, 8.48] | 5.12 | 0.87 | [3.55, 6.69] | 4.6 | 0.52 | [2.84, 6.36] | 5.69 | -1.1 | [3.65, 7.73] | F(4,198)=1.254 | <.001 |
| 5. Arrythmic-Easy Response Task | 1.58 | [1.43, 1.73] | 2.12 | -0.54 | [1.67, 2.57] | 1.58 | 0.54 | [1.23, 1.93] | 1.63 | -0.05 | [1.36, 1.90] | 1.81 | -0.2 | [1.60, 2.02] | F(4,198)=2.084 | 0.089 |
| 6. Arrythmic-Hard Response Task | 2.61 | [1.94, 3.28] | 4.01 | -1.4 | [3.20, 4.82] | 3.84 | 0.17 | [4.85, 2.83] | 4.27 | -0.43 | [2.85, 5.69] | 4.21 | 0.06 | [3.08, 5.34] | F(4,192)=3.599 | 0.036 |
| 1-Way ANOVA | $F(5,197)=5.579$, $p$ = <.001 | | $F(5,198)=5.443$, $p$ = <.001 | | | $F(5,196)=7.496$, $p$ =<.001 | | | $F(5,194)=4.680$, $p$ =<.001 | | | $F(5,189)=5.603$, $p$ =<.001 | | | | |

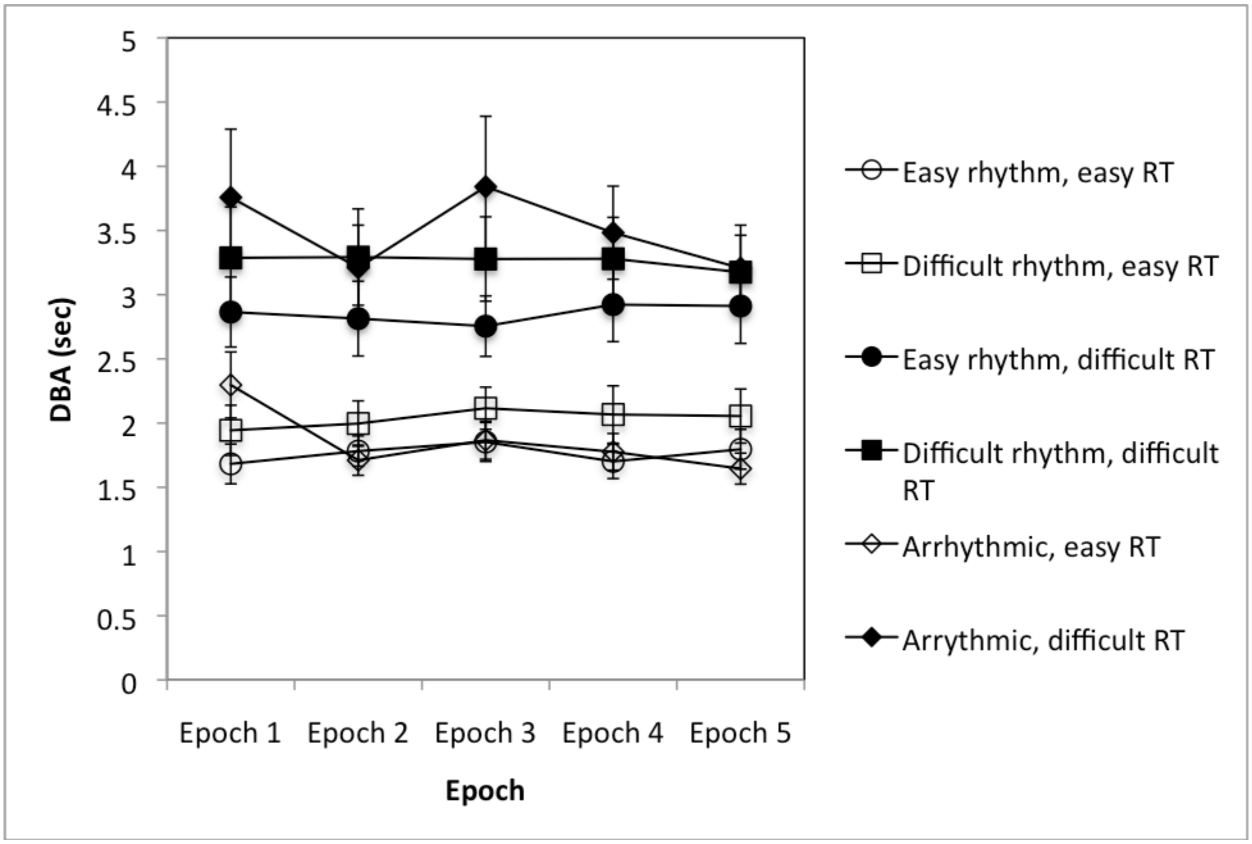


*Figure 6*. Mean DBA depicted across all 5 epochs of interaction for each of the 6 conditions. Conditions are represented as separate lines. Difficult response task (mental arithmetic) conditions have filled-in symbols; note the separation between these and the easy response-task (empty symbol) conditions. Bars depict 95% confidence intervals.

***DBA by Condition***

As DBA scores provide a sense for how well participants are able to anticipate the opening of a WO, larger dwell-time values were expected for rhythmic conditions as compared to arrhythmic conditions; these values were also expected to become larger from the 1st to 2nd epochs before reaching asymptote. What is seen instead in Figure 6 is a visually compelling separation between conditions with difficult RTs (M = 3.2, SD = .99, $CI_{95}$ = [3.51, 2.89]) and easy RTs (M = 1.88, SD = .44, $CI_{95}$ = [1.74, 2.02]). No significant differences between rhythms in conditions sharing the same response task difficulty were observed, indicating that the rhythm manipulations did not significantly contribute to subject anticipation of WO times.

***DBA by Epoch***

The expected trend for DBA between epochs was that scores would grow larger from the 1$^{st}$ to 2$^{nd}$ epoch, reach steady-state, then fall somewhat in the 4th (trick manipulation) epoch. A trend in this direction is seen in the easy rhythm, easy response task and difficult rhythm, easy response task conditions, but no differences between DBA scores within conditions and between epochs were significant. Therefore, there were no trends in the hypothesized direction.

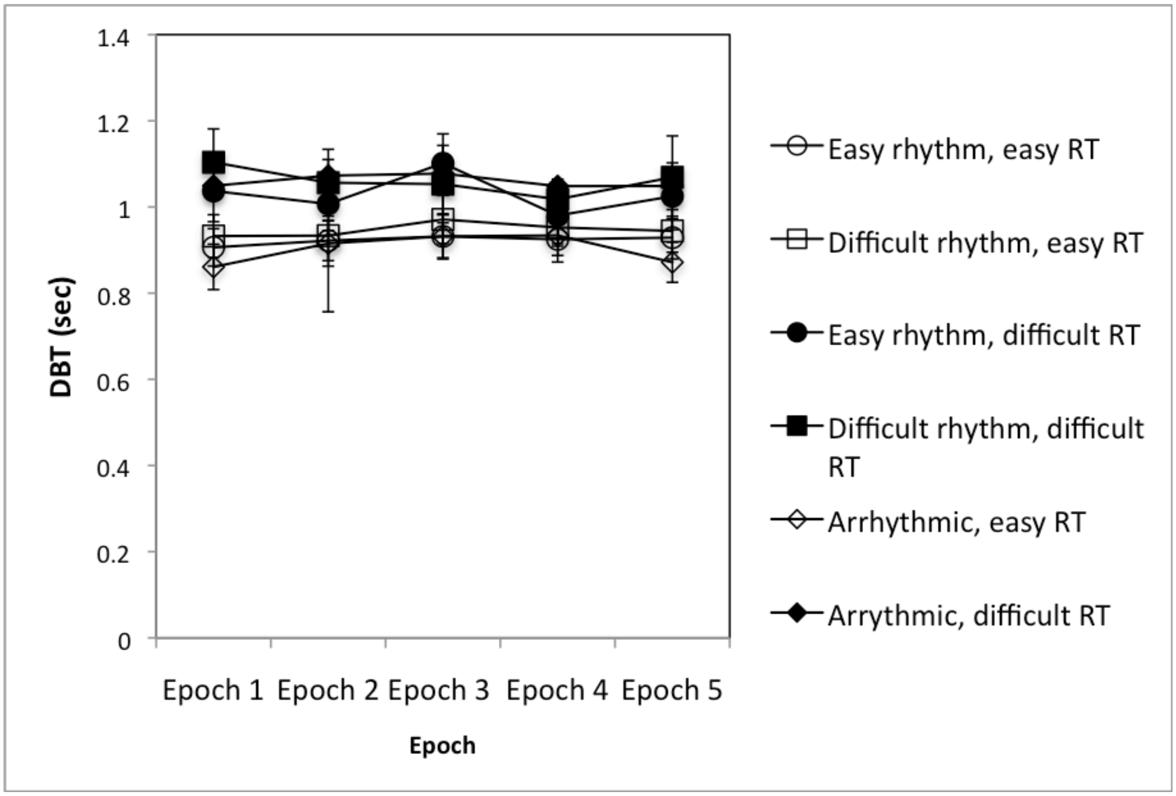


*Figure 7*. Mean DBT depicted across all 5 epochs of interaction for each of the 6 conditions. Conditions are represented as separate lines. Difficult response task (mental arithmetic) conditions have filled-in symbols; note the separation between these and the easy response-task (empty symbol) conditions. Bars depict 95% confidence intervals. DBT by Condition

As participants were expected to have superior temporal awareness in the easy rhythm condition than the difficult rhythm condition (which was likewise hypothesized to facilitate temporal awareness better than the arrhythmic conditions), DBT was expected to decrease with increased rhythmicity. This would suggest that they did not have to stop and think about which task to select next, and would not dwell on their recently completed task before selecting the next. However, Figure 7 reveals no instances of conditions sharing the same response task level but differing in rhythms being statistically significant from one another. The hypothesized trend was therefore not supported.

***DBT by Epoch***

The hypothesized trend for DBT by epoch was that DBT times would grow shorter with continued exposure to the task in the easy and difficult rhythmic conditions. No trend was hypothesized for the arrhythmic conditions. Looking at Figure 7, there are no significant differences between epochs in any of the rhythmic conditions. The hypothesized trend was therefore not evident.

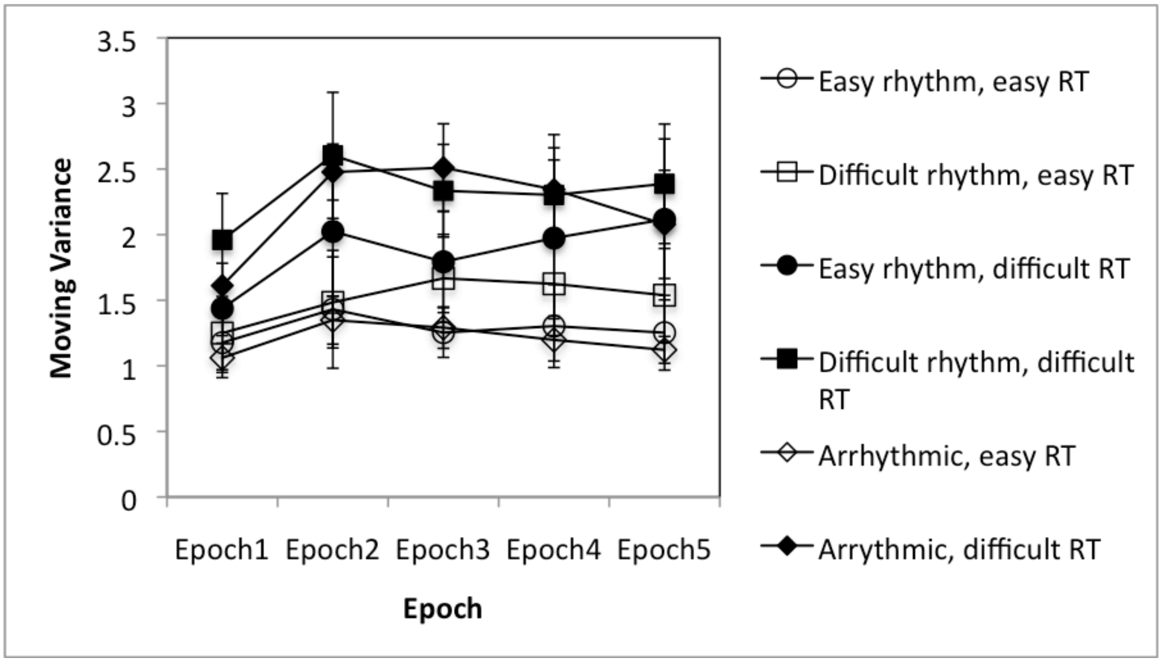


*Figure 8*. Mean Moving Variance depicted across all 5 epochs of interaction for each of the 6 conditions. Conditions are represented as separate lines. Difficult response task (mental arithmetic) conditions have filled-in symbols; note the separation between these and the easy response-task (empty symbol) conditions.

***Moving Variance of Task Change by Condition***

Moving variance of task change was examined by condition to ascertain the effects of specific combinations of manipulations on the variance in task selection (task-change) times. As rhythmic presentation of response tasks was expected to support TA and facilitate rhythmic entrainment, it was hypothesized that all rhythmic conditions would yield lower moving variance scores than arrhythmic conditions, and easy rhythm conditions would have lower scores than the difficult rhythm conditions. These differences were not expected to occur in the 1$^{st}$ epoch, when participants were still acquiring TA, but become evident as the experimental task continued into the 2$^{nd}$ and 3$^{rd}$ epochs. The 4$^{th}$ epoch was expected to see increased moving variance scores for rhythmic conditions though not arrhythmic conditions due to the trick manipulation, then variance was expected to decrease in the 5$^{th}$ epoch as TA and/or rhythm was re-acquired. Figure 7 depicts mean moving variance with 95% confidence intervals for each of the 6 conditions across the 5 epochs of interaction. Consistent with other timing measures, a separation between the smaller scores of the easy response task conditions ($M$ = 1.33, $SD$ = .75, $CI_{95}$ = [1.10, 1.56]) and difficult response task conditions ($M$ = 2.14, $SD$ = 1.05, $CI_{95}$ = [1.81, 2.47]) is apparent, without any significant difference between rhythms sharing the same response task level. Values from the one-way ANOVAs and the 95% confidence intervals are presented in Table 3. The hypothesis that the differences between conditions would become more apparent in the 2$^{nd}$ epoch as compared to the 1$^{st}$ epoch is somewhat supported in looking at Figure 7, though the 95% confidence intervals overlap, meaning the increased separations are not statistically significant. Rhythm did therefore not lead to significant changes in moving variance scores in any condition in any given epoch at the .05 alpha level.

***Moving Variance of Task Change by Epoch***

As with TFA, moving variance was expected to be higher in the first epoch of a given rhythmic condition, followed by decreases in the 2nd and 3rd epochs as steady-state performance was reached. The trick in the 4th epoch was expected to raise moving variance scores, followed by a decrease back to steady state. While looking at Figure 7 suggests that the differences between epoch 1 and 2 in all conditions would be significantly larger, the 95% confidence intervals overlap for all but arrhythmic, difficult RT condition, (1st epoch, $M$ = 1.65, $CI_{95}$ = [1.48, 1.82], 2nd epoch, $M$ = 1.84, $CI_{95}$ = [2.01, 2.43]), and these differences in the rhythmic conditions are therefore not significant at the .05 alpha level. This non-significant trend of an increase in moving variance from the 1st to the 2nd epochs in rhythmic conditions runs counter to the hypothesis that moving variance would decrease from the 1st to the 2nd epoch.

Table 3

*Summary table depicting the results from analyses of moving variance of task change. The experimental blocks were divided into five 60-second epochs, with the average number of trials in each epoch varying with the rhythmicity of the condition. The difference (Δ) column was calculated by subtracting the mean of the epoch from that in the previous epoch (e.g., E1-E2). Results from 1-way ANOVAs on epochs in each condition and on conditions in each epoch are provided, along with lower- and upper-bound 95% confidence intervals which provide an indication of significance at the .05 alpha level. Note that Epoch 4 contained the 'trick' trial, which broke the rhythm in the rhythmic conditions.*

| | Epoch 1 | | Epoch 2 | | | Epoch 3 | | | Epoch 4 | | | Epoch 5 | | | 1-Way ANOVA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Condition | Mean | $CI_{95}$ [Lower, Upper] | Mean | Δ | $CI_{95}$ [Lower, Upper] | Mean | Δ | $CI_{95}$ [Lower, Upper] | Mean | Δ | $CI_{95}$ [Lower, Upper] | Mean | Δ | $CI_{95}$ [Lower, Upper] | *F* | p |
| 1. Easy Rhythm-Easy Response Task | 1.176 | [.90, 1.44] | 1.43 | -0.25 | [.98, 1.88] | 1.25 | 0.18 | [1.06, 1.44] | 1.3 | -0.05 | [.98, 1.62] | 1.25 | 0.05 | [.96, 1.54] | $F(4,197)=.343$ | 0.848 |
| 2. Difficult Rhythm-Easy Response Task | 0.864 | [.96, 1.52] | 1.48 | -0.62 | [1.13, 1.83] | 1.67 | -0.18 | [1.33, 1.99] | 1.62 | 0.04 | [1.23, 2.01] | 1.54 | 0.09 | [1.17, 1.89] | $F(4,190)=.848$ | 0.497 |
| 3. Easy Rhythm-Hard Response Task | 1.437 | [1.22, 1.64] | 2.02 | -0.59 | [1.53, 2.51] | 1.79 | 0.23 | [1.4, 2.18] | 1.97 | -0.18 | [1.37, 2.57] | 2.12 | -0.1 | [1.5, 2.72] | $F(4,192)=1.121$ | 0.348 |
| 4. Difficult Rhythm-Hard Response Task | 1.96 | [1.61, 2.31] | 2.6 | -0.64 | [2.12, 3.08] | 2.33 | 0.27 | [1.98, 2.68] | 2.3 | 0.03 | [1.94, 2.66] | 2.39 | -0.1 | [1.92, 2.84] | $F(4,198)=1.254$ | 0.29 |
| 5. Arrythmic-Easy Response Task | 1.014 | [.90, 1.12] | 1.23 | -0.22 | [1.05, 1.41] | 1.26 | -0.03 | [1.09, 1.41] | 1.18 | 0.08 | [1.01, 1.33] | 1.07 | 0.11 | [.96, 1.16] | $F(4,198)=2.084$ | 0.084 |
| 6. Arrythmic-Hard Response Task | 1.656 | [1.48, 1.82] | 1.84 | -0.18 | [2.01, 2.43] | 2.46 | -0.62 | [2.31, 2.79] | 2.55 | -0.09 | [2.12, 2.96] | 2.51 | 0.04 | [2.10, 2.92] | $F(4,192)=3.599$ | 0.007 |
| 1-Way ANOVA | $F(5,197)=5.579$, $p<.001$ | | $F(5,198)=5.443$, $p<.001$ | | | $F(5,196)=7.496$, $p<.001$ | | | $F(5,194)=4.680$, $p<.001$ | | | $F(5,189)=5.603$, $p<.001$ | | | | |

***Performance***

I performed a 2 X 3 mixed model ANOVA to examine the effects of rhythmicity and response task difficulty on task performance (mean proportion of correct responses). Participants were expected to exhibit better performance in the rhythmic conditions as compared to the arrhythmic conditions as the lack of temporal uncertainty would allow for devotion of high-level attentional resources to the response task. The ANOVA revealed a significant main effect for response task $F(1,238) = 112.25$, $p < .05$, but no main effect for rhythm, $F(2,238) = .45$, $p > .05$. A hypothesized interaction between the two factors fell short of significance $F(2,238) = 2.91$, $p = .056$ (See Figure 7). Tukey's simultaneous 95% confidence interval tests revealed no significant differences between conditions sharing the same level of response task difficulty (see Table 4).

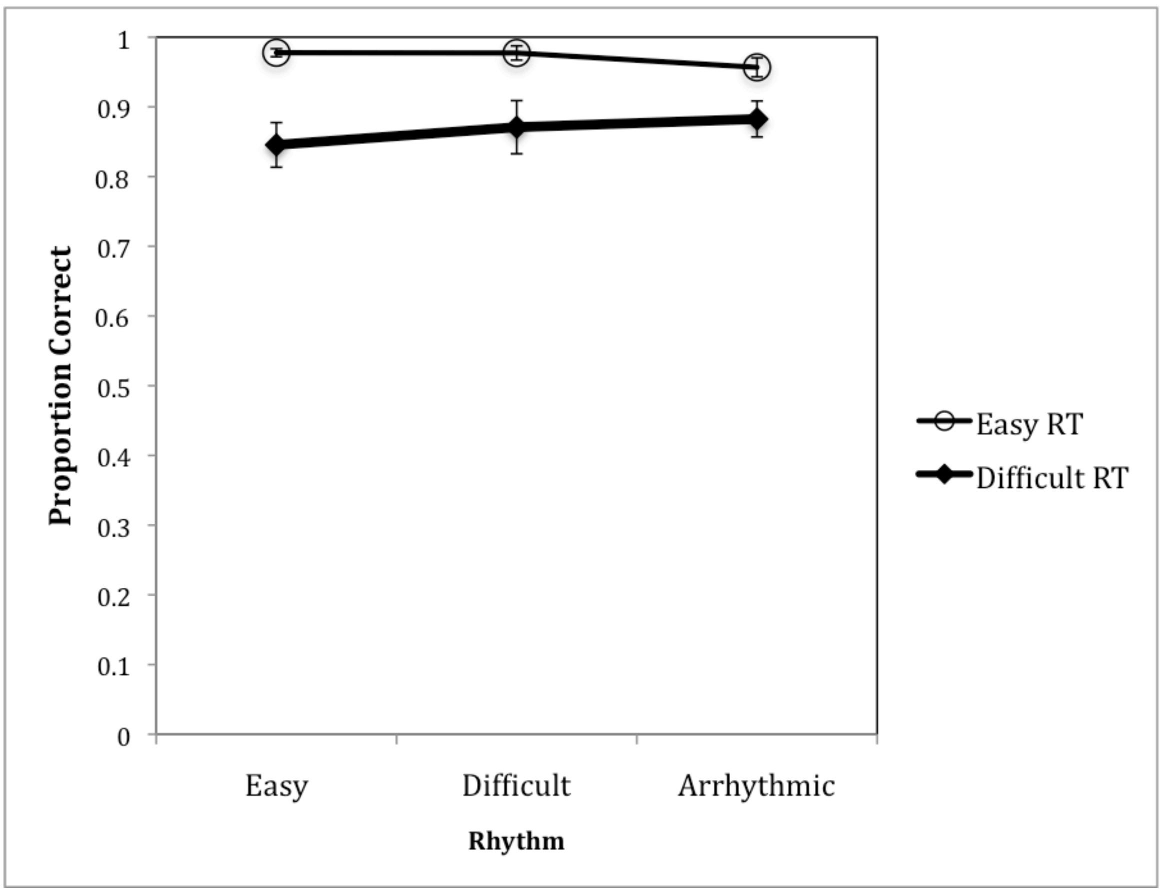


*Figure 7.* Percent correct performance on the 2 levels of response task (RT) difficulty across all 3 levels of rhythm. Bars depict 95% confidence intervals.

Table 4

*Table depicting differences in performance (percent correct) between conditions sharing the same rhythm but differing in response tasks difficulty. There are no significant differences between rhythms within a response task column*

| Rhythm | Response task | | | |
|---|---|---|---|---|
| | Low-Level | High-Level | *t*-statistic | *p*-value |
| Easy | 0.97768 | 0.84544 | -7.71 | < .001 |
| Difficult | 0.97726 | 0.8703 | -6.321 | < .001 |
| Arrhythmic | 0.96181 | 0.84745 | -4.319 | 0.0003 |

***Workload***

I performed a 3 X 2 mixed model ANOVA to examine the effects of rhythm and response task difficulty on each of the workload factors assessed via the NASA-TLX, as well as the overall, weighted score. Table 5 provides a summary of the mean rating scores for each of the factors, as well as their standard deviation and 95% confidence intervals. As participants in rhythmic conditions would presumably not have to expend as many attentional resources on the timing element of the task, it was hypothesized that rhythmic conditions would have significantly lower NASA-TLX ratings than arrhythmic conditions, and easy rhythm condition scores would be lower than difficult rhythm conditions.

Table 5

*Summary of NASA-TLX results for each of the 6 conditions. Means, standard deviations, and 95% confidence intervals are depicted. Overall, weighted scores are presented, along with raw scores for each of the loading factors examined in this experiment. Bolded values indicate the highest score for that particular factor.*

| Workload Factor | Easy rhythm, easy RT | | | Difficult rhythm, easy RT | | | Easy rhythm, difficult RT | | | Difficult rhythm, difficult RT | | | Arrhythmic, easy RT | | | Arrhythmic, difficult RT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | $CI_{95}$ | *M* | *SD* | $CI_{95}$ | *M* | *SD* | $CI_{95}$ | *M* | *SD* | $CI_{95}$ | *M* | *SD* | $CI_{95}$ | *M* | *SD* | $CI_{95}$ |
| **Overall** | 20.95 | 15.5 | 4.79 | 24.52 | 16.73 | 5.18 | 47.52 | 21.4 | 6.62 | **53.65** | 16.74 | 5.19 | 47.88 | 21.24 | 6.58 | 52.49 | 19.87 | 6.16 |
| Mental Demand | 15.93 | 15.1 | 4.66 | 17.46 | 14.13 | 4.38 | 49.27 | 27.5 | 8.53 | **52.97** | 25.61 | 7.94 | 32.93 | 24.69 | 7.65 | 50.63 | 25.94 | 8.04 |
| Temporal Demand | 29.45 | 23.8 | 7.37 | 27.59 | 19.11 | 5.92 | 50.65 | 27.5 | 8.53 | 59.44 | 23.71 | 7.35 | **64.12** | 25.49 | 7.9 | 56.25 | 23.1 | 7.16 |
| Own Performance | 23.27 | 28.3 | 8.77 | 24.1 | 27.11 | 8.4 | 36.63 | 23.9 | 7.39 | 38.46 | 22.97 | 7.12 | 38.48 | 22.92 | 7.1 | **41.85** | 21.69 | 6.72 |
| Frustration | 12.8 | 12.7 | 3.92 | 16.87 | 15.99 | 4.96 | 45.65 | 26.2 | 8.11 | 46.18 | 25.11 | 7.78 | 44.25 | 25.68 | 7.96 | **47.75** | 24.43 | 7.57 |
| Effort | 22.35 | 21.3 | 6.6 | 26.59 | 19.05 | 5.9 | 54.05 | 26.5 | 8.2 | 56.46 | 24.61 | 7.63 | 46.85 | 25.12 | 7.78 | **67.2** | 28.2 | 8.739 |

*Overall.* Results of the omnibus ANOVA revealed a significant main effect for rhythm $F(2,237) = 14.62$, $p <.01$, and response task $F(1,237) = 65.81$, $p <.01$, as well as a significant interaction between the two factors $F(2,237) = 9.89$, $p <.05$. Figure 8 depicts the mean NASA-TLX scores for each of the factors across all 6 conditions. The line depicting overall NASA-TLX scores is bolded. A comparison of 95% confidence intervals revealed that significant differences in overall NASA-TLX scores were found between the easy rhythm, easy RT ($M = 20.95$, $SD = 15.5$, $CI_{95} = 4.79$) and all other conditions with the exception of the difficult rhythm, easy RT condition ($M = 24.52$, $SD = 16.73$, $CI_{95} = 5.18$). There were no significant differences between conditions sharing the same response task, with the notable exception of the arrhythmic, easy response task condition ($M = 47.88$, $SD = 19.87$, $CI_{95} = 6.16$) yielding ratings that were 25.11 units higher than the other easy RT conditions on average. The hypothesis that rhythmic conditions would exhibit lower scores than arrhythmic conditions was thus supported for easy RT conditions, though not the hypothesis that easy rhythm condition would yield lower scores than difficult rhythm conditions.

*Mental Demand*. For the factor of mental demand, ratings were again higher in mental math conditions as compared to the easy RT conditions, and the two rhythmic easy RT conditions were significantly lower than the arrhythmic, easy RT conditions. This main effect for response task was significant, $F(1,237) = 96.54$, $p <.05$, as was the effect for rhythm $F(2,237) = 3.47$, $p <.05$. The significant interaction between the two factors $F(2,237) = 3.66$, $p <.05$ suggests that the levels of rhythm affected the response tasks differently. A comparison of 95% confidence intervals in table 5 reveals the same differences described in the overall, weighted NASA-TLX section above.

*Temporal Demand.* For the factor of temporal demand, there was a significant main effect for response task, $F(1,237) = 23.61$, $p < .05$, and rhythm, $F(2,237) = 16.18$, $p < .05$. The interaction effect between response task and rhythm was also significant, $F(2,237) = 14.67$, $p < .05$. The comparison of 95% confidence intervals yields the same differences as described in the overall NASA-TLX section, and the mental demand section. Temporal demand ratings were thus higher under certain combinations of rhythm and response task difficulty than others; specifically the arrhythmic, easy RT condition, and all difficult RT conditions were higher than the rhythmic, easy, RT conditions.

*Own Performance.* For own performance, there were significant main effects for response task F(1,237) = 10.73, p = .001, and rhythm $F(2,237) = 4.14$, $p = <.05$. The interaction was not significant F(2,237) = 1.23, p > .05. A comparison of 95% confidence intervals from Table 5 revealed that the easy rhythm, easy RT condition ($M = 23.27$, $SD = 28.3$, $CI_{95} = 8.77$) and the difficult rhythm, easy RT condition ($M = 24.1$, $SD = 27.11$, $CI_{95} = 8.4$) were significantly different from the arrhythmic, difficult RT condition ($M = 41.85$, $SD = 21.69$, $CI_{95} = 6.72$) a the .05 alpha level. This suggests that arrhythmia drove ratings of own performance higher in easy RT conditions.

*Frustration.* The ANOVA revealed a significant main effect for loading task $F(1,237) = 57.56$, $p < .05$, and rhythm $F(2,237) = 13.31$, $p = <.001$. A significant interaction was also observed $F(2,237) = 10.34$, $p < .001$. Looking at Table 5 for a comparison of 95% confidence intervals, it is seen that the easy rhythm, easy RT condition ($M = 12.8$, $SD = 12.7$, $CI_{95} = 3.92$) and the difficult rhythm, easy RT condition ($M = 16.87$, $SD = 15.99$, $CI_{95} = 4.96$) were significantly lower than all other conditions. No other significant differences were observed. Looking at Figure 8 to unpack this interaction, it is clear that it is the arrhythmic level of rhythm on the easy RT that drives this interaction.

*Effort.* For effort, a significant main effect for response task was observed $F(1,237) = 27.99$, $p = <.001$, as was a main effect for rhythm $F(2,237) = 5.01$, $p = <01$. No significant interaction effect was observed F(2,237) = .47, p > .05. Comparison of 95% confidence intervals from Table 5 revealed that the easy rhythm, easy RT condition ($M = 23.27$, $SD = 28.3$, $CI_{95} = 8.77$) and the difficult rhythm, easy RT condition ($M = 24.1$, $SD = 27.11$, $CI_{95} = 8.4$) were rated significantly lower than all other conditions; further, the arrhythmic, difficult RT condition ($M = 67.2$, $SD = 28.2$, $CI_{95} = 8.73$) was rated significantly higher than all other conditions.

In general, participants rated rhythmic conditions lower than arrhythmic conditions on many of the loading factors, though not when taken as an overall, weighted score.

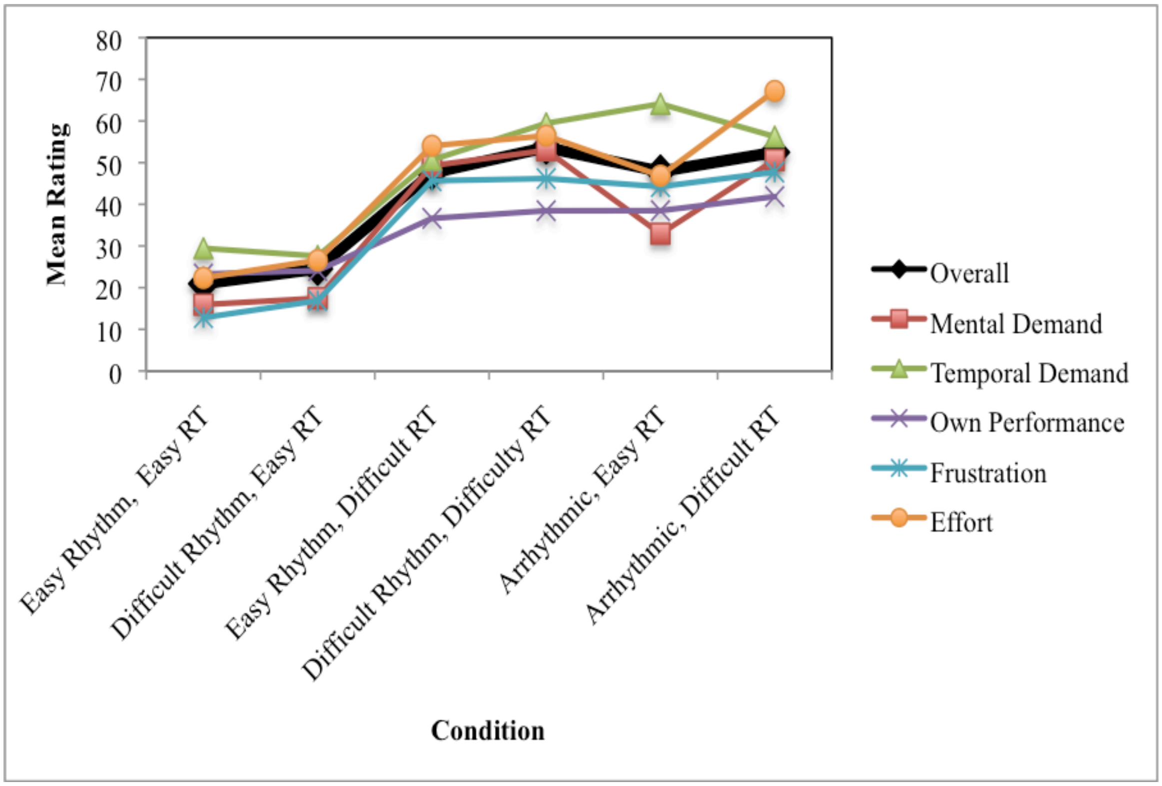


*Figure 8*. Line chart depicting the mean NASA-TLX rating for each of the loading factors along with the overall, weighted score, by condition.

***Post-Experiment Questionnaire.***

Following completion of all experimental conditions, participants were asked to complete an open-ended questionnaire with the following 3 items: *Do you recall certain conditions as being more 'mentally taxing' than others? Which ones, and why?; At any point, did you feel as though you had gotten into a 'rhythm' in performing the tasks?; Do you believe that rhythm can impart any benefits when performing tasks such as these?* Responses were codified into 1 of 4 categories for the first item: Category 1=Those conditions containing math; Category 2=The arrhythmic conditions; Category 3= No conditions were more mentally taxing than the others; Category 4= Those conditions with a fast pace. The other two questionnaire items were codified as 1='yes', or 0= 'no'. Though the results described here are simplified, rich and valuable insights were provided by many of the participants as to how they experienced the rhythm of the task and the potential benefits that they feel it can impart. 1 participant did not complete the post-test item, and thus the reported percentages are based on 39 participants.

*Item 1. Do you recall certain conditions as being more 'mentally taxing' than others? Which ones, and why?* For this item, the vast majority of participants (29, or 74.35%) identified the conditions with mental arithmetic response tasks as being more mentally taxing. 4 participants identified 'faster' conditions (10.25% of respondents), and another 4 participants listed arrhythmic conditions as more mentally taxing. 2 participants (5.12%) stated that they did not recall any of the conditions as being more mentally taxing than the others.

*Item 2. At any point, did you feel as though you had gotten into a 'rhythm' in performing the tasks?* For this item, 36 participants (92%) responded affirmatively. As the rhythmic nature of the experimental task was not made explicit at the beginning of the session, this result offers support for the hypothesis that participants would acquire rhythm without conscious attention.

*Item 3. Do you believe that rhythm can impart any benefits when performing tasks such as these?* For this third and final item, 32 participants (approximately 82%) responded that they did feel rhythm can impart performance benefits.

## Chapter 4: Discussion

### *Rhythm Facilitates Temporal Awareness*

There was evidence that rhythm supported temporal awareness (TA), although the hypothesized relationships between the timing measures of Time to First Action (TFA), Dwell Before Action (DBA) and Dwell Before Task Change (DBT) and TA were not supported. It was expected that TFA times would be smaller, DBA times would be longer, and DBT would be shorter in the rhythmic conditions (which were expected to facilitate TA, as opposed to the arrhythmic conditions, which were not). The hypothesized trend of shorter TFA was only found for measures in the rote-copying RT conditions, which makes sense given the general lack of uncertainty in both the timing and response task. However, the trend for mental arithmetic conditions was in exactly the opposite direction (larger TFA values for rhythmic, mental math conditions than in mental math, arrhythmic conditions). Though disconcerting at first, these findings are actually consistent with Grosjean and Terrier (1999), who found that subjects who developed TA managed their "rest" periods better. These subjects exhibited longer rest periods (though not necessarily *more* rest periods) than those who did not develop TA in a simulated process control environment. It could be that subjects in rhythmic conditions, when faced with a mentally taxing RT such as mental math, were better able to manage their rest periods given the duress imposed upon them by both the time and RT manipulations. This hypothesis assumes they had a better understanding of exactly how long they had to perform the task before the progress bars maxed out than they did in arrhythmic conditions, and thus delayed performance of the task until they felt more comfortable with their response. This hypothesis is supported by the mental workload data (to be described below) in which arrhythmic conditions had higher workload ratings than rhythmic conditions of the same response task difficulty.

DBA scores ran counter the hypothesis as well, with longer times being observed in arrhythmic mental arithmetic conditions as opposed to rhythmic mental arithmetic conditions. The same explanation from Grosjean and Terrier (1999) applies here: subjects chose to rest for longer periods after performance of this task, and thus "dwelled" for a shorter period on the newer task. DBT proved insensitive to alterations in the rhythm of the tasks, and exhibited none of the trends described for the other measures. Higher DBT times for difficult RT conditions are likely explained by the fact that participants needed to wait for feedback on whether or not they answered the math problem correctly before moving on.

Evidence for rhythmic entranment to the task (operationalized as regularity in task selection behavior) over time is sparse; moving variance of task change proved insensitive to changes in rhythm, and was affected more by response task difficulty, with mental arithmetic conditions leading to significantly higher moving variance scores. Interestingly, these scores exhibited a trend in the direction of increased moving variance with decreasing rhythm. As performance of multi-digit mental arithmetic draws on high-level, central-executive resources (DeStefano & LeFevre, 2004) (those same resources drawn on during performance of difficult rhythmic tapping tasks (e.g., Krampe et al., 2005)), it is possible that participants exhibit greater variability in their task selection behaviors due to the bi-directional interference in mental math/duration estimation described by Brown (1997) and the resultant inability to develop TA.

An additional component of this hypothesis is that participants would acquire rhythmicity in rhythmic conditions without conscious attention (Schmidt et al., 2007). While some evidence of temporal awareness in rhythmic conditions did emerge in the objective data, whether it arose in an unconscious manner was difficult to assess. Participants were not told ahead of time that the study was attempting to identify the effects of rhythm on performance, and thus any rhythm that did arise may have occurred without conscious attention. The post-test questionnaire inquired as to whether or not participants felt they had "gotten into a rhythm", and the vast majority responded affirmatively. The validity of this method is questionable, however, as merely asking the question amounts to cueing the participants as to how they should describe their control strategy.

### *Rhythm Makes Available Attentional Resources*

The results reported here provide little support for the hypothesis that rhythm makes available attentional resources for the performance of difficult secondary tasks. While rhythmic presentation of response tasks served to support temporal awareness under some conditions, temporal awareness for its own sake means little for the design of process-control systems or decision aids if it does not promote timely and accurate task performance. While Okada (1992) found performance benefits for the performance of a dynamic and mentally taxing task when rhythm for the process was acquired, there are fundamental differences between the task he presented his subjects with, and the task facing subjects in the present experiment. While the task that Okada presented his participants with was dynamic, it was in fact predictable when well-practiced and performed optimally. Subjects were presented with the reference times for the durations with which they were to increase a controlled quantity of water into the flow-lines 200 times each for 5 different durations. The task thus became streamlined into an automatic or skill-based task that could be performed without conscious attention (e.g., Reason, 1990; Rasmussen, 1983; Wickens and Hollands, 2000). Multi-digit mental math, on the contrary, will necessarily draw on central-executive resources (DeStefano & LeFevre, 2004), and the problems were chosen quasi-randomly so as not to introduce practice effects. Future research should examine the effects of rhythm on a high-level task that is capable of being moved from a knowledge-based to a skill-based mode (Rasmussen, 1983).

It is still surprising that rhythm did not free-up attentional resources for the performance of mental math in rhythmic conditions. There are three hypotheses for why this occurred, the first of which has to do with how much 'time crunch' was imposed upon participants. While an effort was made to randomize the progress bar speeds and windows of opportunity in the arrhythmic conditions to create a true lack of emergent rhythmic properties, these were randomized around parameters that we felt were reasonable for the performance of mental arithmetic. Sessions conducted while the computer program was being developed with progress bar speeds similar to those in the rhythmic conditions were found to be too mentally taxing, and it was predicted that participants would grow frustrated and employ a pronounced task-shedding strategy. It was thus decided that progress bar rates would be randomized around a set of speeds deemed reasonable for accurate response task performance, which may have been too comfortable for participants in retrospect. The lack of temporal uncertainty (c.f. Zakay & Block, 1994) due to the surplus of available time for response tasks left more resources for the performance of mental arithmetic than were likely available in conditions with more obvious temporal importance. It is probable that if the timing element of the task had been stressed during the instructional period that participants would have placed more importance with the temporal component, thus drawing high-level resources away from the response task and reducing performance. An inconsistency with this assessment is the finding that participants reported higher subjective mental workload scores to arrhythmic conditions compared to the easy rhythm condition. The second possibility is that following the Yerkes-Dodson Law (1908) participants experienced the optimal level of arousal for task performance in conditions pairing a moderate time pressure with a difficult response task. Carlson and Cassenti (2004) found that in highly rhythmic presentations of stimuli in an event-counting task that at least some of the participants' attentional resources were allocated to the monitoring of flow disruption; this third hypothesis suggests that participants in the easy rhythm conditions devoted some of their resources to flow monitoring to the detriment of their response task performance compared to the difficult rhythm and arrhythmic conditions.

***The Impacts of Broken Rhythm***

The measures used in this experiment proved insufficient to answer this question. For all of the timing measures, TFA, DBA, DBT and Moving Variance of task change, it was hypothesized that participants would exhibit increases (with the exception of DBA, in which a decrease was expected) in the $4^{th}$ epoch, which contained the trick. Slight jumps in the scores were observed in this epoch, but there was never enough of a change in participants' behavior to sufficiently impact the means for the entire epoch. Smaller epochs, on the order of 20 to 30 s could perhaps be utilized in future analyses to better describe the impacts of temporal errors resulting from broken rhythm. It remains an important question, with implications ranging from the mortar accident described earlier (Accident Investigation Board, 2005) to the more mundane "slips" described by Reason (1990). Anecdotally, it is worth noting from participant observations that the majority of participants expressed surprise at the trick, quickly entered the requested response code or sum, and moved on without a pronounced change in task selection behavior.

### ***Rhythm Reduces Subjective Mental Workload***

That participants ascribed greater mental workload scores to arrhythmic conditions than rhythmic conditions under the easy level of response task is not surprising given the theory. Carlson and Cassenti (2004) described rhythmic presentation of events in counting tasks as lessening the strain on executive resources by streamlining the processing of intentions; as no goal representation needs to be maintained in working memory, high-level cognitive resources are free to be used elsewhere. I would argue that the rote-copying of an arbitrary 2-digit code is similar to event counting in terms of cognitive resource expenditure, and it is thus not surprising that participants rated conditions with rhythmic presentation of this task as less demanding across all loading factors.

Avni-Babad and Ritnov (2003) demonstrated that routine or rhythmic presentation of high priority events (HPEs) allowed subjects to cease perceiving these events as individual experiences that required executive resources to count and encode in long-term memory. The experience of these events became automated, and thus required fewer attentional resources for processing. It is likely that similar mechanisms were present in rhythmic, easy RT conditions, which presented response tasks in a routine manner. Subjects may have experienced the entire block of trials as one long task with intermittent automated responses, rather than separate trials each with their own unique timer and response.

That subjects did not rate difficult response tasks differently over different rhythmic presentations can be explained by DeStefano and LeFevre (2004), who claim that multi-digit mental math problems with a carry operation will always draw on high-level central executive resources. It appears that rhythmic presentation of these arithmetic problems was insufficient to attenuate the cognitive strain associated with the use of these resources.

### ***Limitations and Generalizability***

As with any abstract simulation task, generalizability to performance in the real-world is modest. There is little value placed on successful task performance, and few negative repercussions for task failures. Future research in a higher fidelity process control environment would likely reveal more about the effects of rhythm on task performance and mental workload. An additional limitation of the study was the perhaps too-strong manipulation of the high-level response task. Few processes require operators to perform mentally-taxing tasks for such sustained periods of time, particularly tasks that do not arise naturally as the result of two or more temporal components of one's task, as they did in Okada's study (1992). More realistic responses that naturally result from the timing task rather than appearing arbitrarily would likely tell us more about the main effect of rhythm, and the potential interactions with the difficulty of the procedures. Also, the primary measure of rhythmicity in this study, that of moving variance, proved insensitive to subtle manipulations designed to assess the effects of broken rhythm on behavior (such as the trick that we introduced in the $4^{th}$ epoch); future studies will focus on identifying more suitable measures for answering this question. Finally, an interesting finding of this study was that a history of music and dance as assessed by the background questionnaire significantly co-varied with the other independent variables for nearly all of the dependent measures; this information was not acquired with great enough specificity to separate participants into distinct groups, so future research will attempt to cull more information from participants along these lines for potential inclusion as a between subjects variable. Post-experiment questionnaires indicated that participants grew bored and thus not engaged with the experimental task; as data revealed steady-state performance inside of 3 epochs, subsequent studies will use fewer blocks of trials to circumvent this under-arousal.

### ***Conclusion***

The purpose of this research was to investigate the factors that allow for emergence of automatic performance, whether such performance could be classified as rhythmic, and the effects of such performance on both temporal and nontemporal task elements. This study revealed that rhythmic presentation of stimuli in an abstract time-sharing task can facilitate TA (in terms of timeliness of response) and lead to lower subjective mental workload ratings in easy response task conditions. There were no discernible benefits of rhythm on task performance, and a non-significant trend for poorer performance of mental arithmetic under rhythmic conditions was observed. The moving variance measure chosen for this study to measure rhythm proved insensitive to changes in rhythmic behavior over time, so rhythmic entrainment to the task was not observed. Future studies must identify a more sensitive measure of rhythmicity in order to describe the conditions that influence unintentional entrainment to rhythmic task properties. Future research will also use a more realistic test bed such as NPP or process control console simulations, with context-appropriate response tasks. Video analysis of operators in naturalistic settings would also further the research. An important contribution to the literature is the demonstrated utility of the temporal awareness measures (i.e., TA, DBA) and their sensitivity to rhythm manipulations.

### ***Recommendations***

Design applications resulting from the present study are not readily identifiable due to the basic nature and low generalizabilty of the study. Deleterious effects of rhythm were observed in performance on the difficult response task, and the effects of broken rhythm due to the trick manipulation in the $4^{th}$ epoch of interaction led to non-significant trends of higher TFA scores on low-level response tasks. This would lead one to the assumption that rhythm in general is not a quality that should be facilitated in an operational environment. However, operators naturally seek out temporal markers in their environment regardless (e.g., De Keyser, 1995), and potential benefits as identified by Okada (1992) warrant further exploration of this idea. Assuming potential benefits of rhythm in certain tasks, temporal awareness in rhythmic environments can be assisted and entrainment strengthened with an oscillating visual stimulus (Schmidt et al., 2007). Such a stimulus could be mapped to the environmental temporal phenomenon of interest and included on an operator's display.

Endsley, Bolte and Jones (2003) recommend that projected future system states should be represented on user displays, as Level 3 situation awareness requires cognitive resources beyond those found in the lower levels and would allow for reallocation of these resources for concurrent tasks. Rhythmic environments by their nature present little uncertainty for the user, and projection aids are generally only necessary in dynamic or uncertain environments. Processes that entail rhythmic presentation of tasks can perhaps be supported by indicating when rhythm is likely to be broken, or alerting operators when a variable is introduced that may alter the environmental rhythm in some way.

While Okada (1992) found rhythmic entrainment to be beneficial in the performance of a NPP flow-line changeover, this was a highly reliable simulated environment. An operator must develop sufficient trust in the system to ensure appropriate levels of compliance and reliance on the proposed rhythmic aid found in their display (Dixon & Wickens, 2006; Lee & See, 2004). Relying solely on rhythm to perform a complex task will likely result in poor error monitoring (Carlson & Cassenti, 2004) and an incomplete or errant situation model (Endsley, 1995) if insight into the actual system state is not provided at critical phases of the process.

**References**

Accident Investigation Board (2005). *Mortar accident at the Rovajärvi shooting zone* (B3/2005Y). Helsinki, Finland: Author.

American Psychological Association (2001). Publication Manual of the American Psychological Association (5th ed.). New York: American Psychological Association.

Avni-Babad, D. & Ritov, I. (2003). Routine and the perception of time. *Journal of Experimental Psychology: General, 132* (4), 543-550.

Bolton, T. L. (1894). Rhythm. *American Journal of Psychology, (6)*, 145-238.

Braem, P. B. (1999). Rhythmic temporal patterns in the signing of deaf early and late learners of Swiss German sign language. *Language & Speech, 42* (2-3), 177-208.

Brown, S. W. (1997). Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks. *Perception & Psychophysics, 59* (7), 1118-1140.

Carlson, R. A. & Cassenti, D. N. (2004). Intentional control of event counting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30* (6), 1235-1251.

Censullo, M., Lester, B. & Hoffman, J. (1985). Rhythmic patterning in mother-newborn interaction. *Nursing Research, 34* (6), 342-346.

De Keyser, V. (1995). Time in ergonomics research. *Ergonomics, 38* (8), 1639-1660.

DeStefano, D. & LeFevre, J. (2004). The role of working memory in mental arithmetic. *European Journal of Cognitive Psychology, 16* (3), 353-386.

Dixon, S. R. & Wickens, C. D. (2006). Automation reliability in unmanned aerial vehicle control: A reliance-compliance model of automation dependence in high workload. *Human Factors 48*(3), 474-486.

Endsley. M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37* (1), 32-64.

Endsley, M. R., Bolte, B., & Jones, D. G. (2003). *Designing for situation awareness: An approach to user-centered design*. Boca Raton: Taylor & Francis.

Field, A. (2005). Discovering statistics using SPSS (2nd ed.). London: Sage.

Grosjean, M., Rosenbaum, D.A., & Elsinger, C. (2001). Timing and reaction time. *Journal of Experimental Psychology: General,1*(2), 256-272.

Grosjean, V. & Terrier, P. (1999). Temporal awareness: Pivotal in performance? *Ergonomics, 42* (11), 1443-1456.

Isaacs, E. (1920). The nature of the rhythm experience. *Psychological Review, 27* (4), 270-299.

Ivry, R. B. (1996). The representation of temporal information in perception and motor control. *Current Opinions in Neurobiology, 6*, 851-857.

Krampe, R. T., Engbert, R. & Kliegl, R. (2001). Age-specific problems in rhythmic timing. *Psychology and Aging, 16* (1), 12-30.

Krampe, R. T., Mayr, U. & Kliegl, R. (2005). Timing, sequencing, and executive control in repetitive movement production. *Journal of Experimental Psychology: Human Perception and Performance, 31* (3), 379-397.

Lee, J. D. & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors, 46*(1), 50-80.

Levinthal, B. R. & Rantanen, E. M. (2004). Measurement of taskload and performance in a dynamic multi-task experiment. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, New Orleans, LA: HFES.

Loftus, G. R. (1996). Psychology will be a much better science when we change the way we analyze data. *Current Directions in Psychological Science*, 5(6), 161-171.

MacDougall, R. (1900). Rhythm. Psychological Review, 7(3), 309-312.

Okada, Y. (1992). Human characteristics at multi-variable control when the operator changes overt the plant lines. *Ergonomics, 35* (5-6), 513-523.

Patel, A. D. (2006). Musical rhythm, linguistic rhythm, and human evolution. *Music Perception, 24* (1), 99-104.

Patel, A. & Iversen, J. (2006). A non-human animal can drum a steady beat on a music instrument. *Proceedings of the 9th International Conference on Music Perception and Cognition*. Bologna, August 22-26, 2006.

Pressing, J., Summers, J. & Magill, J. (1996). Cognitive multiplicity in polyrhythmic pattern performance. *Journal of Experimental Psychology: Human Perception and Performance, 22*(5), 1127-1148.

Rantanen, E. M. (2007).Temporal awareness in ATC: Literature review and a proposed model. *Proceedings of the 14th International Symposium on Aviation Psychology* (pp.570-576). Dayton, OH, April 23-26, 2007.

Rantanen, E. M. & Levinthal, B. (2005). Time-based modeling of human performance. *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting*. Orlando, FL: HFES.

Rasmussen, J. (1983). Skills, rules, and knowledge; Signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics, 13*(3), 257-266.

Reason, J. (1990). *Human Error*. Cambridge: Cambridge University Press.

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review, 12* (6), 969-991.

Riess Jones, M., Jagacinski, R. J., Yee, W., Floyd, R. L. & Klapp, S. T. (1995). Tests of attentional flexibility in listening to polyrhythmic patterns. *Journal of Experimental Psychology: Human Perception and Performance, 21*(2), 293-307.

Sarter, N.B., & Woods, D.D. (1991). Situation awareness: A critical but ill-defined phenomenon. *The International Journal of Aviation Psychology, 1*(1), 45-57.

Schmidt, R. C., Richardson, M. J., Arsenault, C. & Galantucci, B. (2007). Visual entrainment to an environmental rhythm. *Journal of Experimental Psychology: Human Perception and Performance, 33*(4), 860-870.

Sheridan, T. B. (2002). *Humans and Automation: System Design and Research Issues*. (Santa Monica: Wiley Inter-Science).

Tabachnick, B. G., & Fidell, L. S. (1989). *Using multivariate statistics (4th ed.).* Boston: Allyn and Bacon.

Vorberg, D. & Wing, A. M. (1996). Modelling variability and dependence in timing. In H. Heuer & S.W. Keele (Eds*.) Handbook of perception and action: Vol. 3. Motor Skills* (pp.181-261). London: Academic Press.

Wickens, C. D. (1998). Commensense statistics. Ergonomics in Design, 4,18-22.

Wickens, C. D. & Hollands, J. G. (2000). *Engineering Psychology and Human Performance (3rd ed.)*. Upper Saddle River, NJ: Prentice Hall.

Yerkes, R. M. & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459-482.

Zakay, D., & Block, R.A. (1994). New perspective on prospective time estimation. In De Keyser, V., d'Ydewalle, G., & Vandierendonck, A. (Eds.), *Time and the Dynamic Control of Behavior* (pp.129-141). Gottingen: Hogrefe & Huber Publishers.

Zakay, D., Block, R.A., & Tsal, Y. (1996). Prospective duration estimation and performance. In Gopher, D., & Koriat, A. (Eds.), *Attention and Performance XVII. Cognitive Regulation of Performance: Interaction of Theory and Application* (pp.557-580). Cambridge: The MIT Press.

**Appendix A: Dotplots of Raw Data**

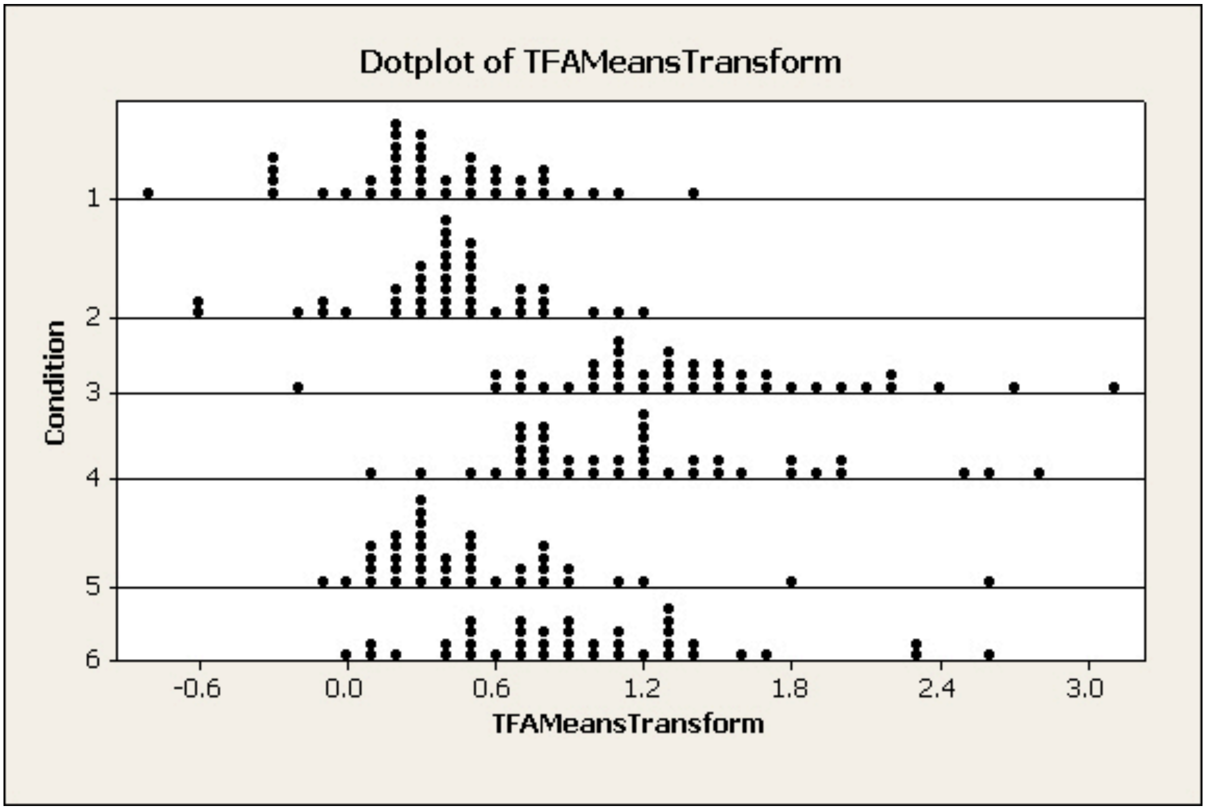


*Figure A1*. Dotplot depicting mean Time to First Action (TFA) scores (all epochs combined) for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Scores for this measure were normalized using a log base 10 transform. Numbers on the X-axis thus refer to transformed time in seconds. Note the relative lack of spread in conditions 1, 2 and 5 (the easy response task conditions).

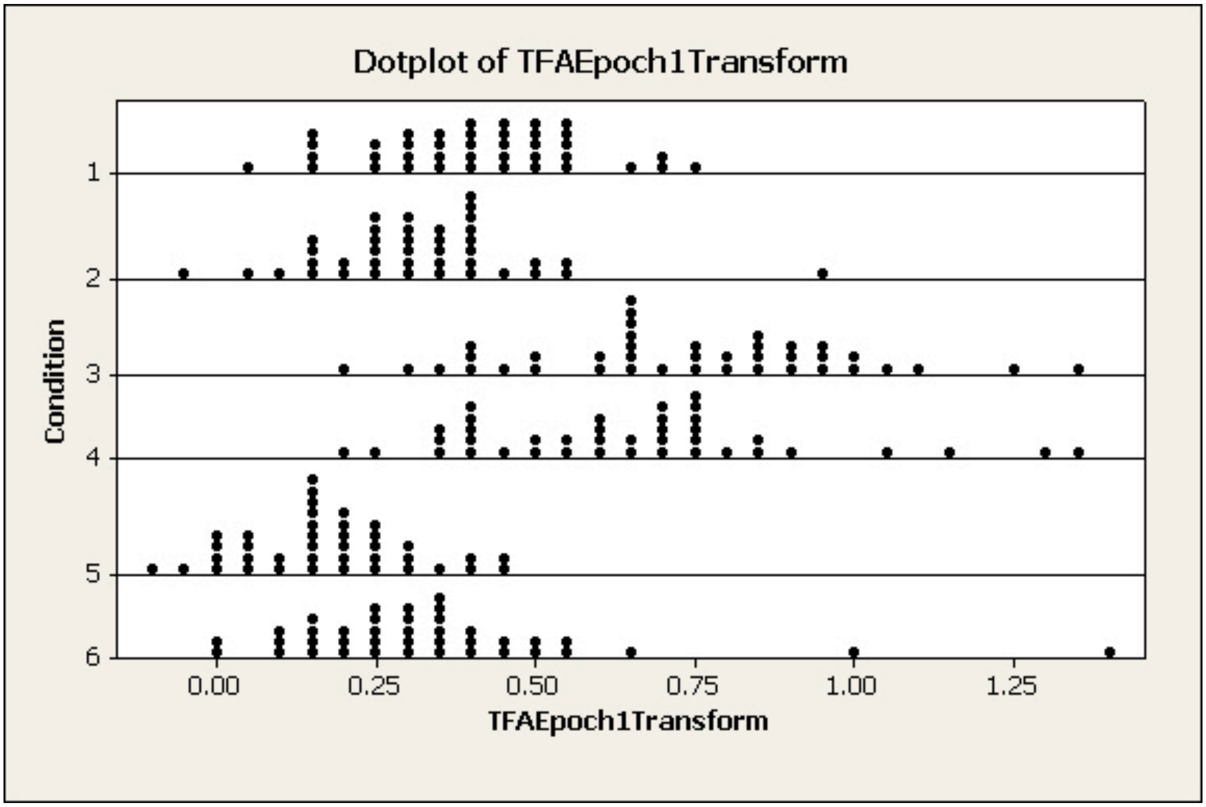


*Figure A2*. Dotplot depicting mean Time to First Action (TFA) scores in the first epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Scores for this measure were normalized using a log base 10 transform. Numbers on the X-axis thus refer to transformed time in seconds.

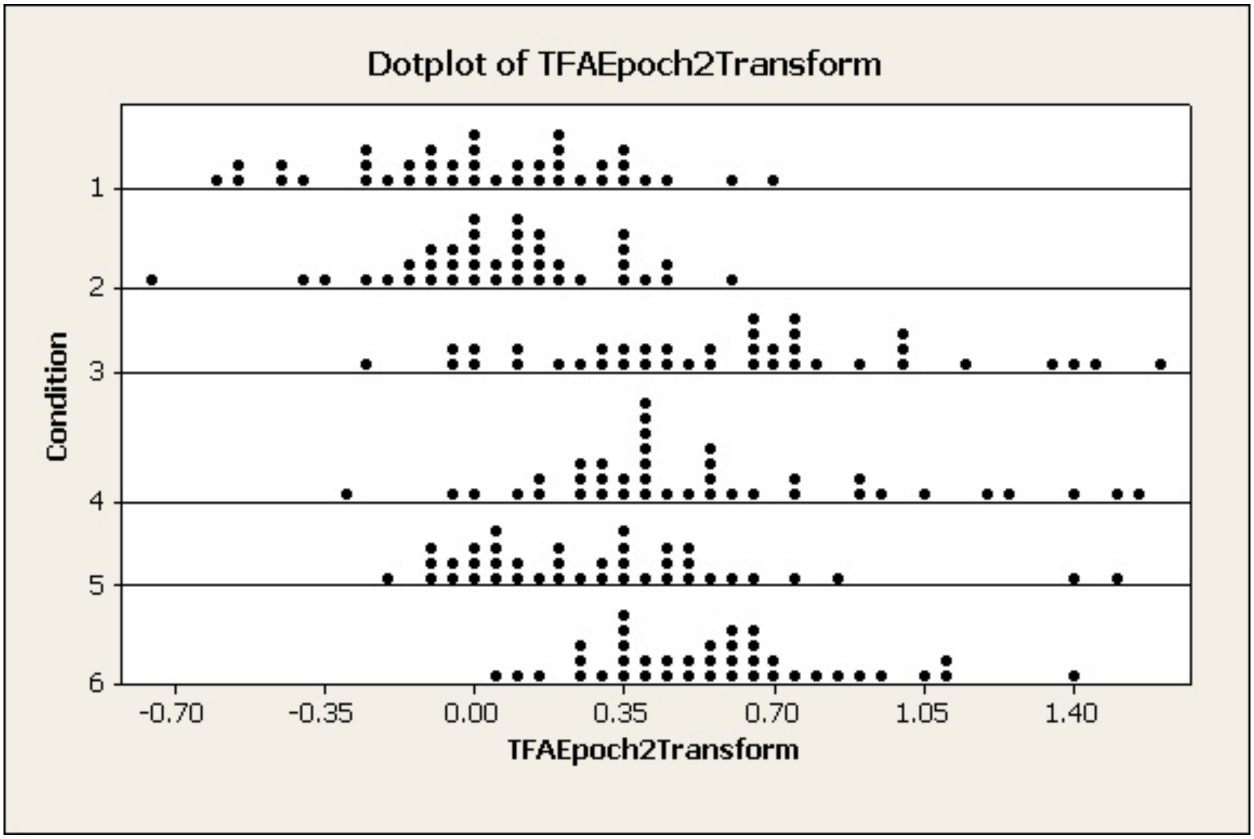


*Figure A3*. Dotplot depicting mean Time to First Action (TFA) scores in the second epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Scores for this measure were normalized using a log base 10 transform. Numbers on the X-axis thus refer to transformed time in seconds.

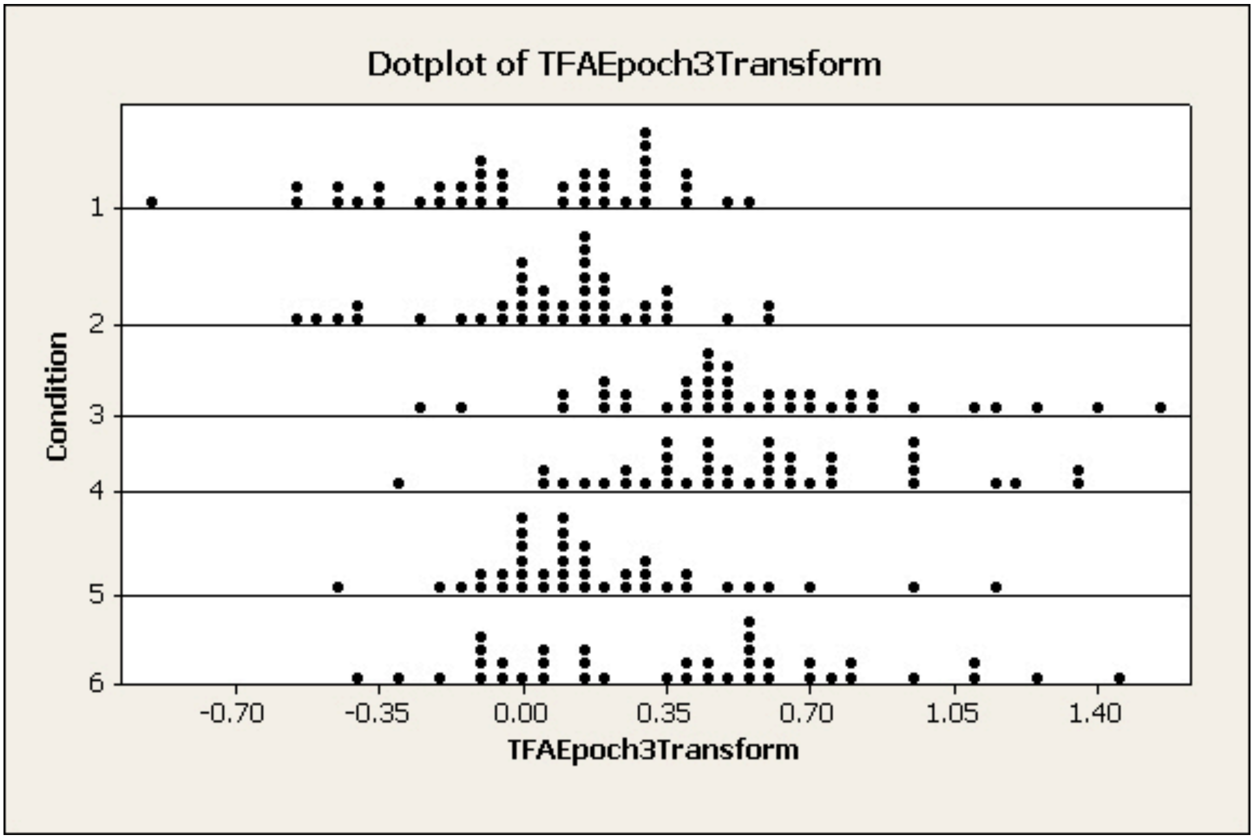


*Figure A4*. Dotplot depicting mean Time to First Action (TFA) scores in the third epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Scores for this measure were normalized using a log base 10 transform. Numbers on the X-axis thus refer to transformed time in seconds.

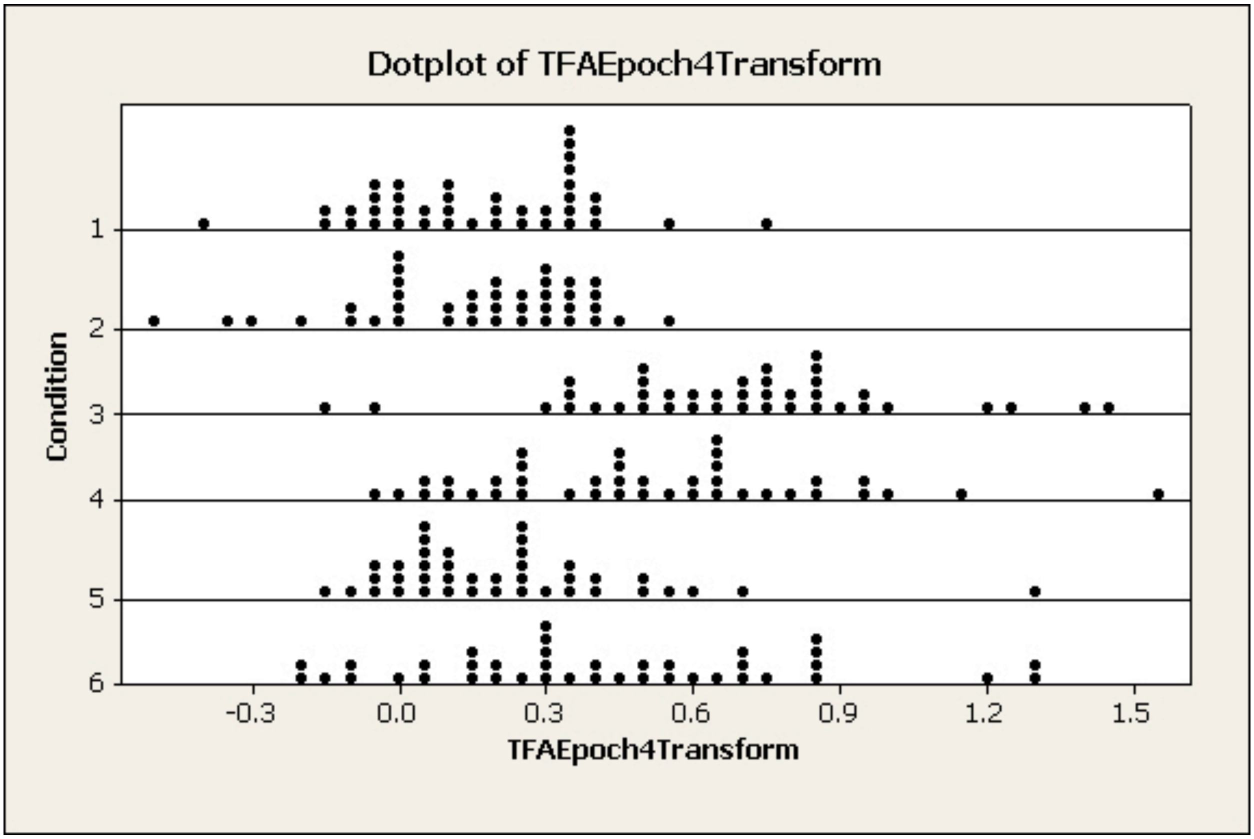


*Figure A5*. Dotplot depicting mean Time to First Action (TFA) scores in the fourth epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Scores for this measure were normalized using a log base 10 transform. Numbers on the X-axis thus refer to transformed time in seconds.

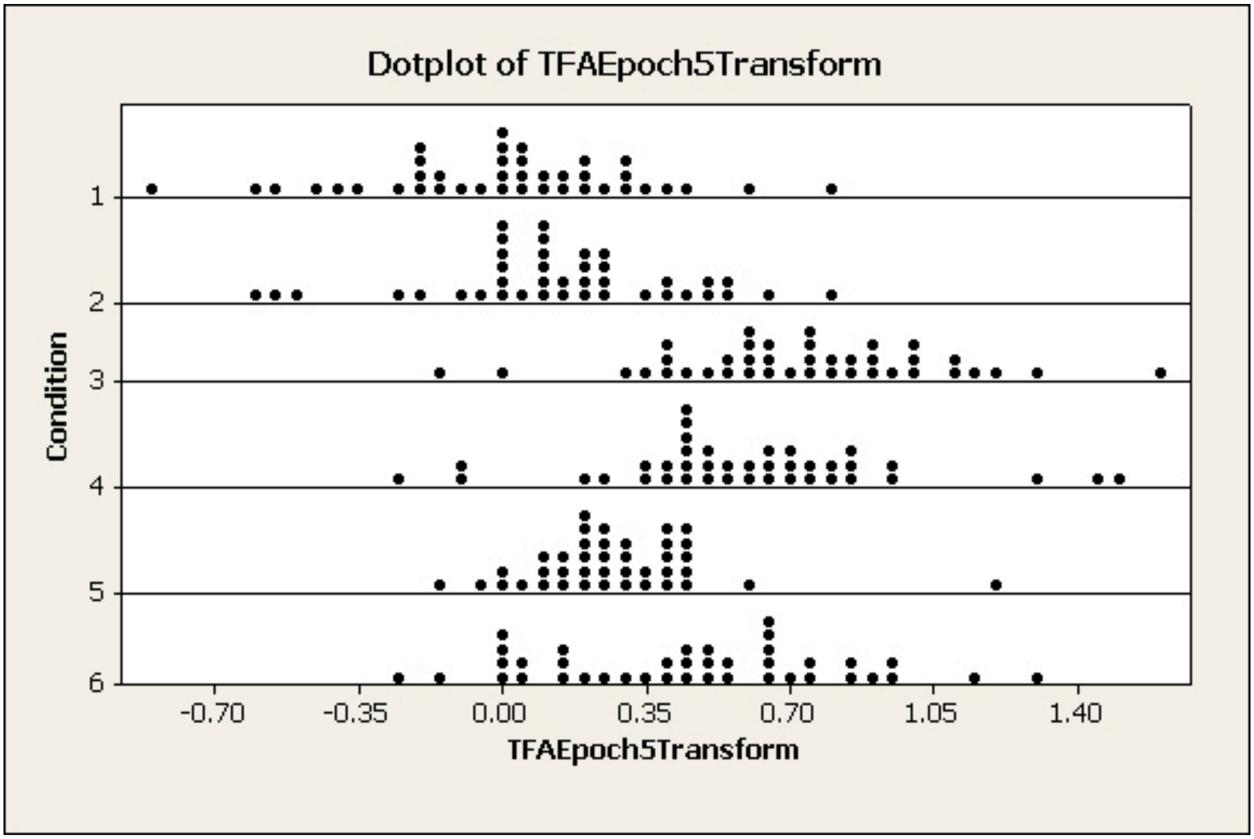


*Figure A6*. Dotplot depicting mean Time to First Action (TFA) scores in the fifth epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Scores for this measure were normalized using a log base 10 transform. Numbers on the X-axis thus refer to transformed time in seconds.

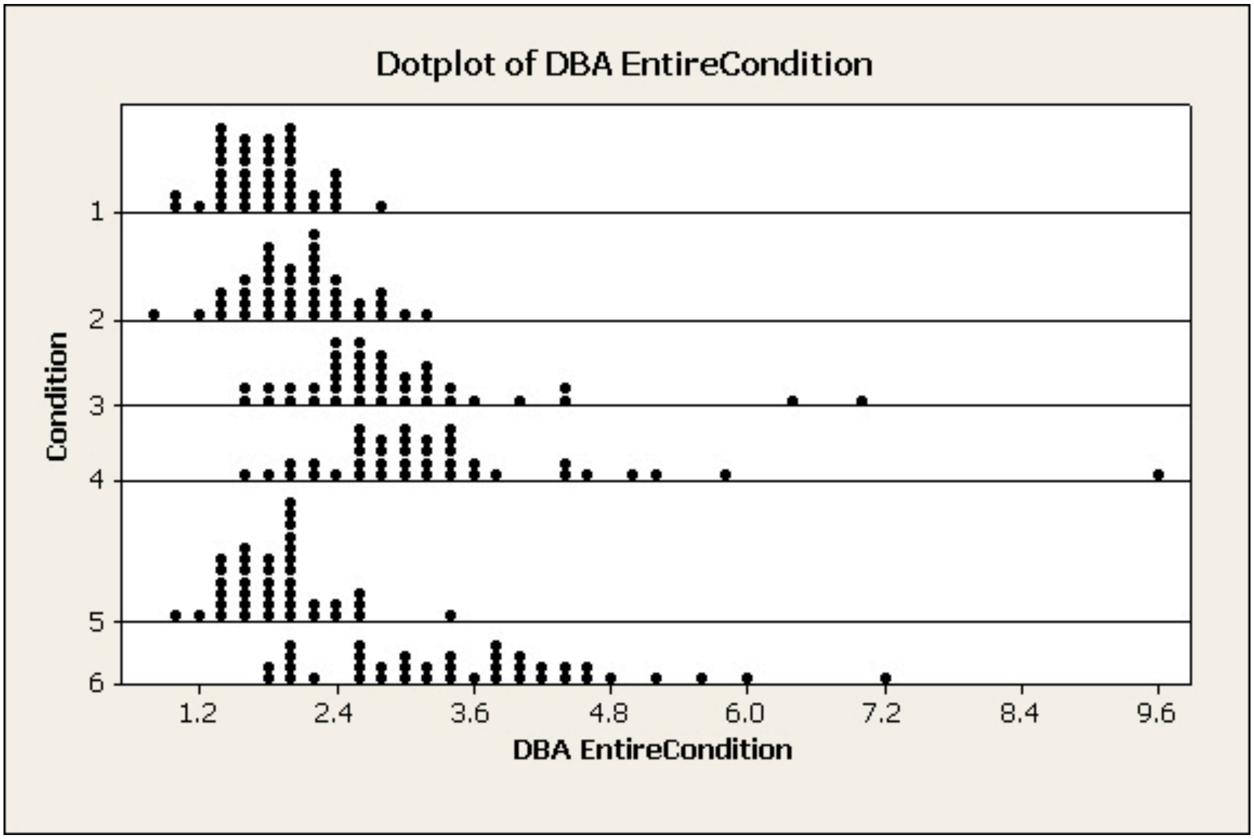


*Figure A7*. Dotplot depicting mean Dwell Before Action (DBA) scores (all epochs combined) for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

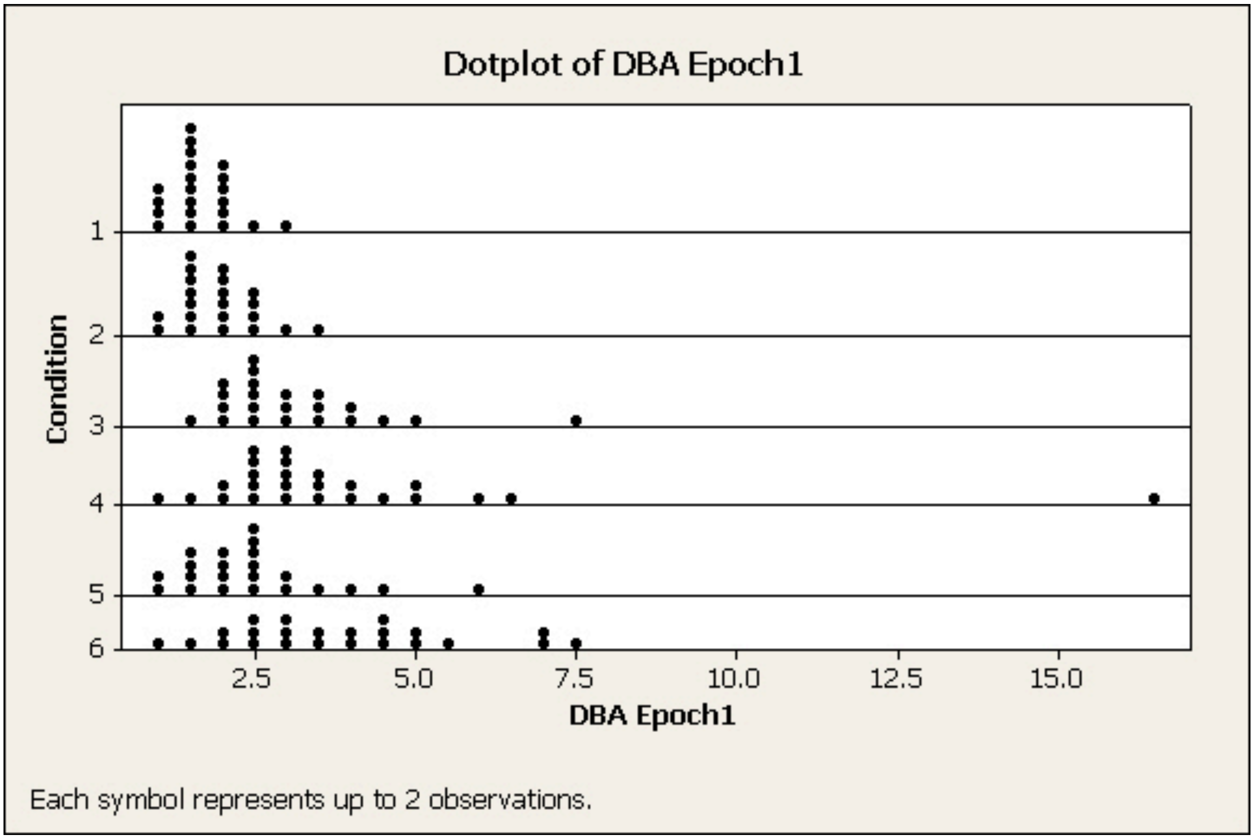


*Figure A8*. Dotplot depicting mean Dwell Before Action (DBA) scores in the first epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

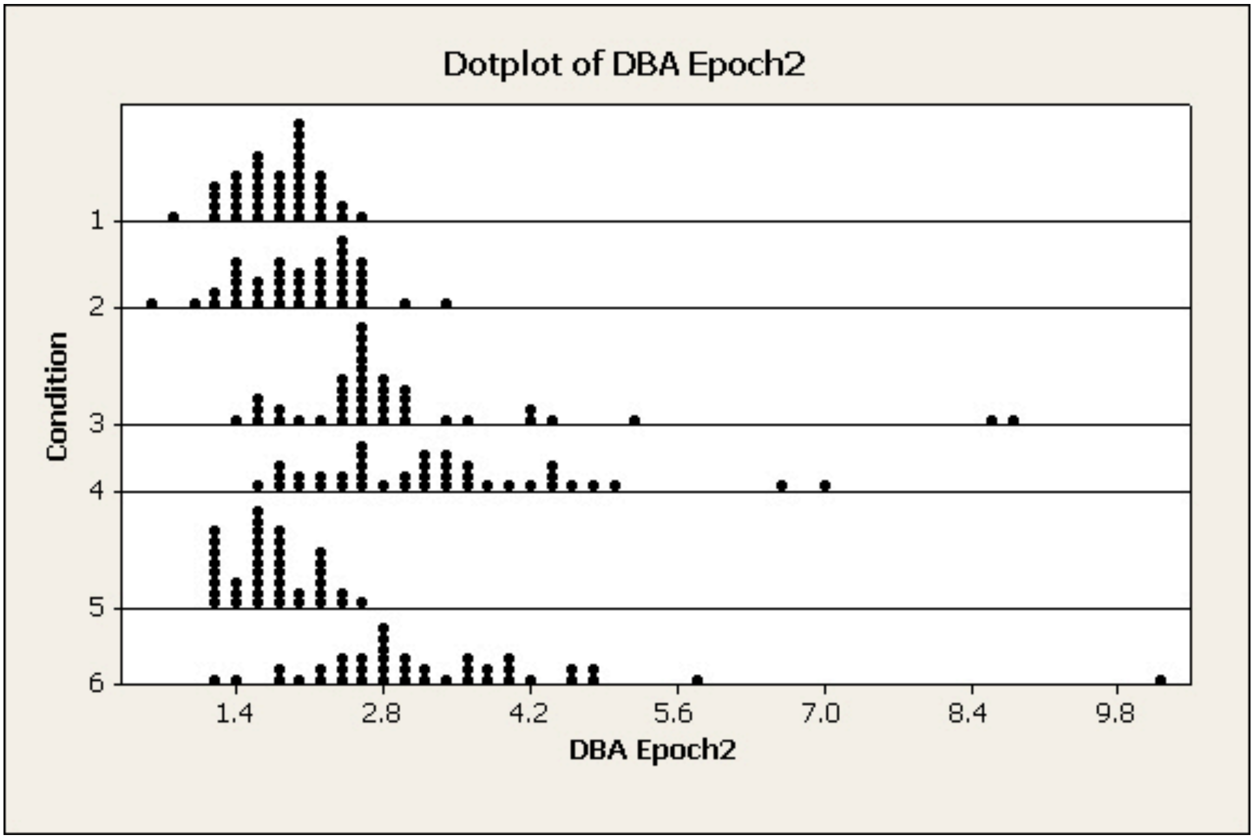


*Figure A9*. Dotplot depicting mean Dwell Before Action (DBA) scores in the second epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

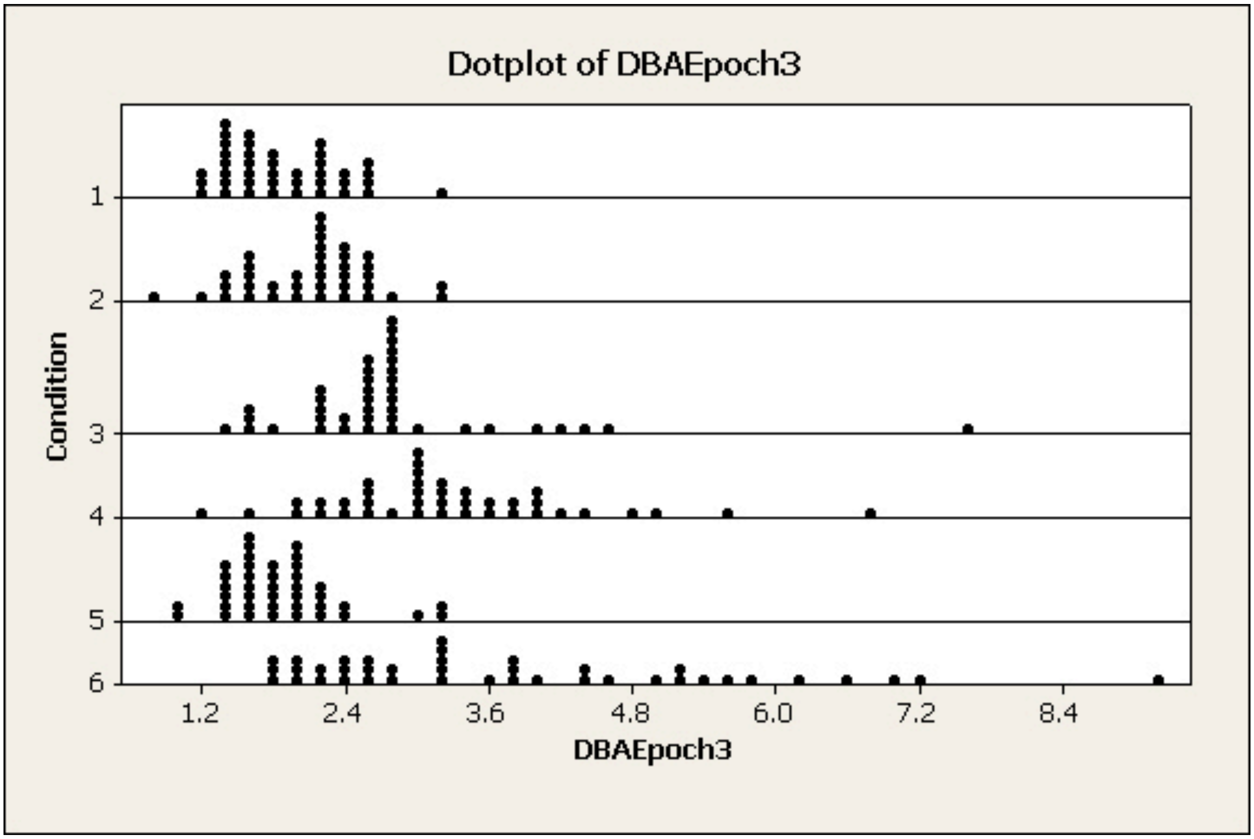


*Figure A10*. Dotplot depicting mean Dwell Before Action (DBA) scores in the third epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

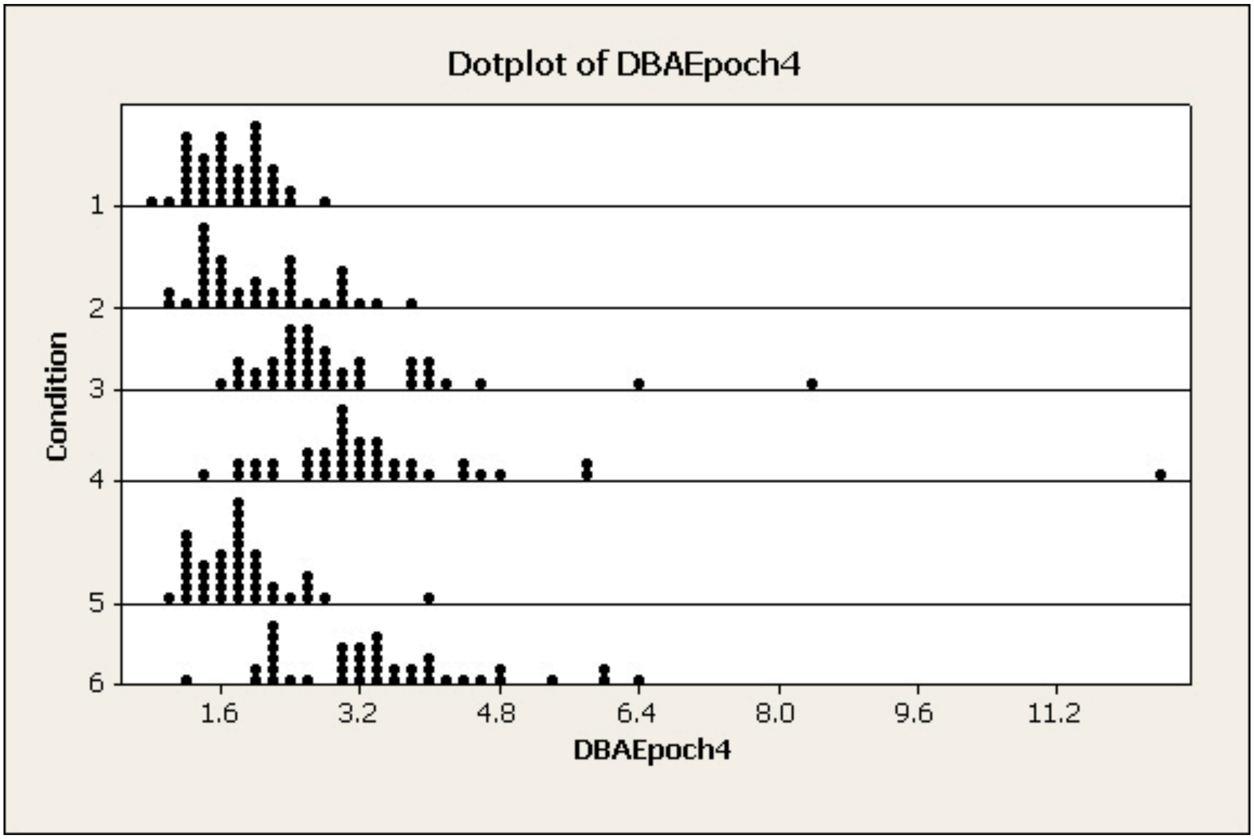


*Figure A11*. Dotplot depicting mean Dwell Before Action (DBA) scores in the fourth epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

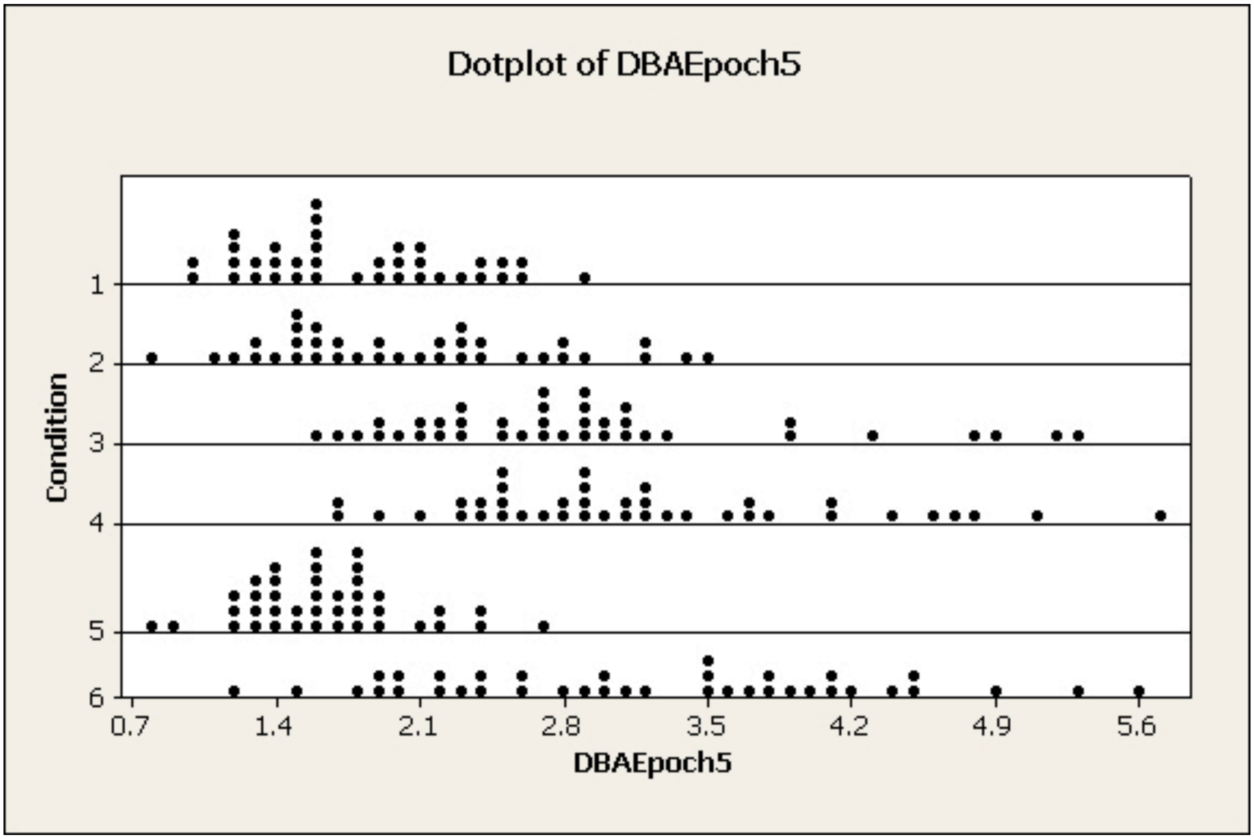


*Figure A12*. Dotplot depicting mean Dwell Before Action (DBA) scores in the fifth epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

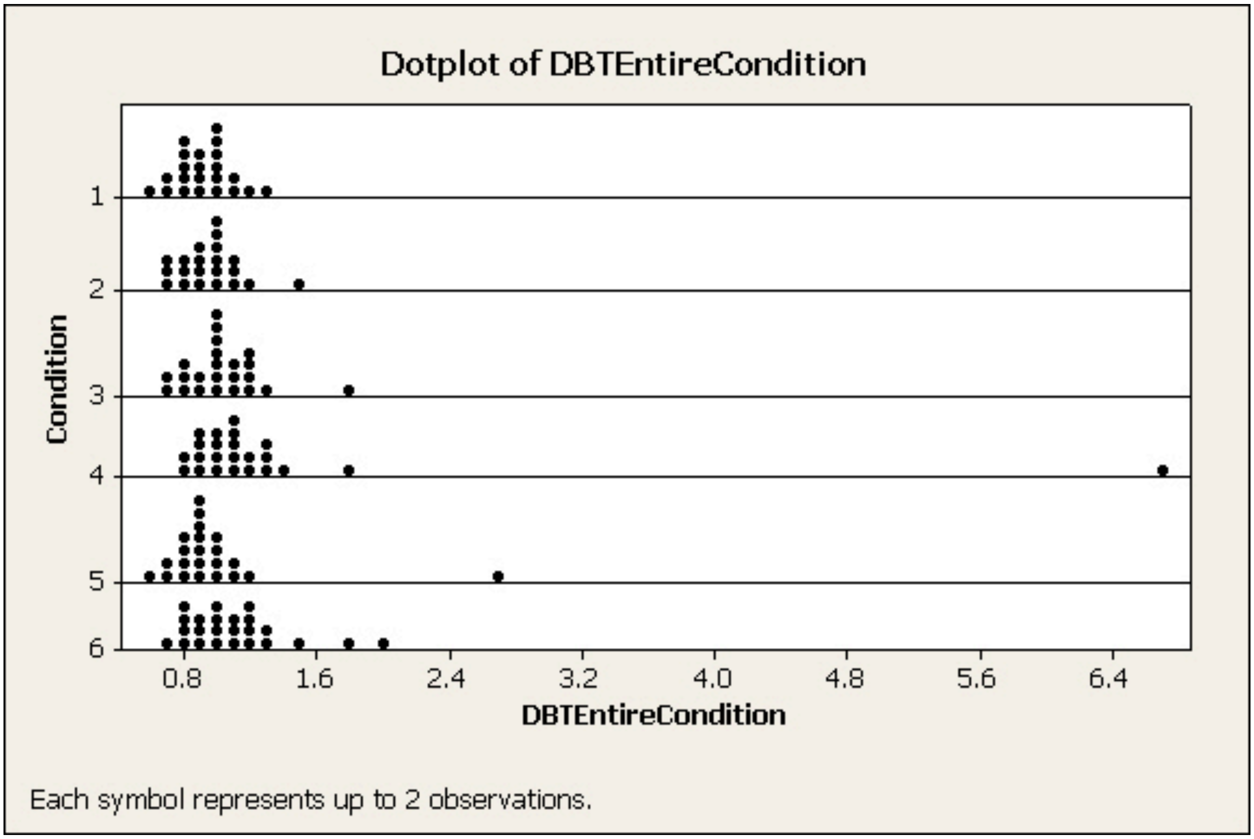


*Figure A13*. Dotplot depicting mean Dwell Before Taskchange (DBT) scores (all epochs combined) for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Note the general lack of spread regardless of condition. Values on the X-axis are time in seconds.

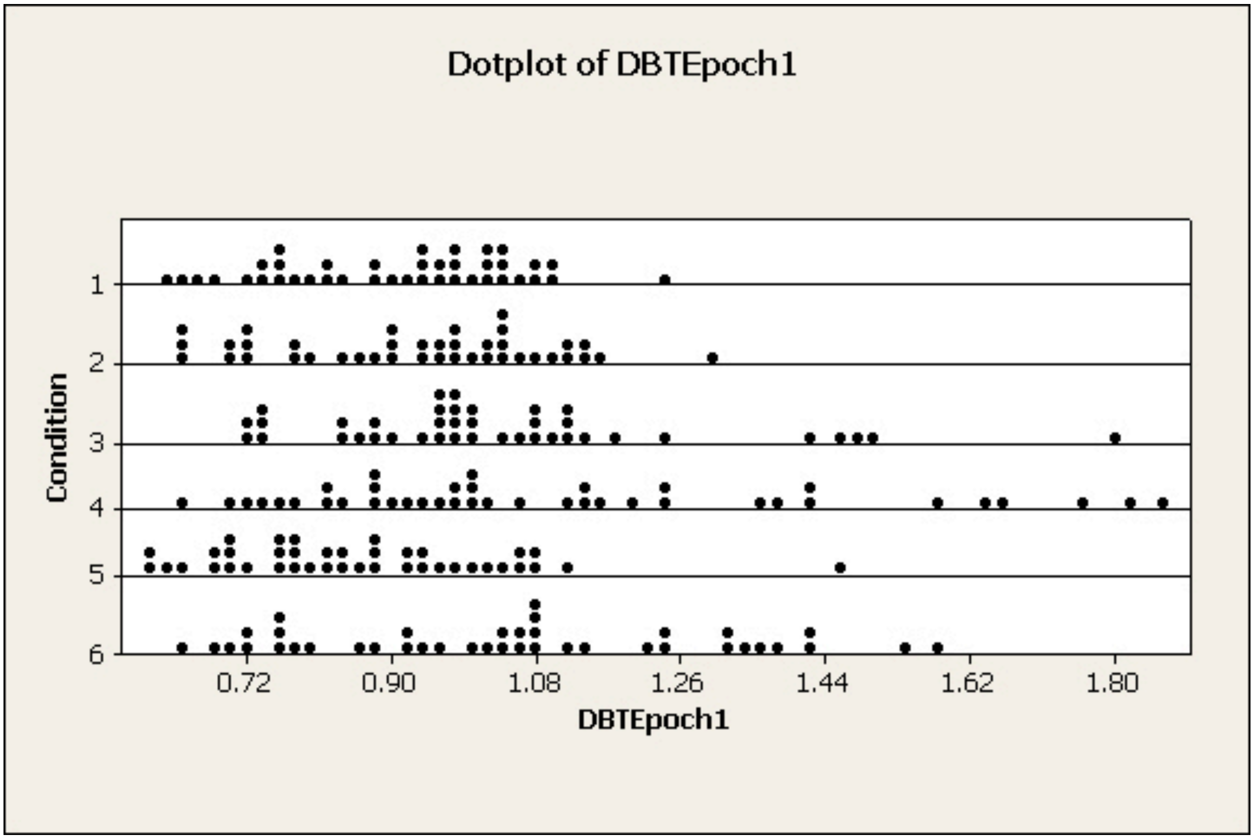


*Figure A14*. Dotplot depicting mean Dwell Before Taskchange (DBT) scores in the first epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

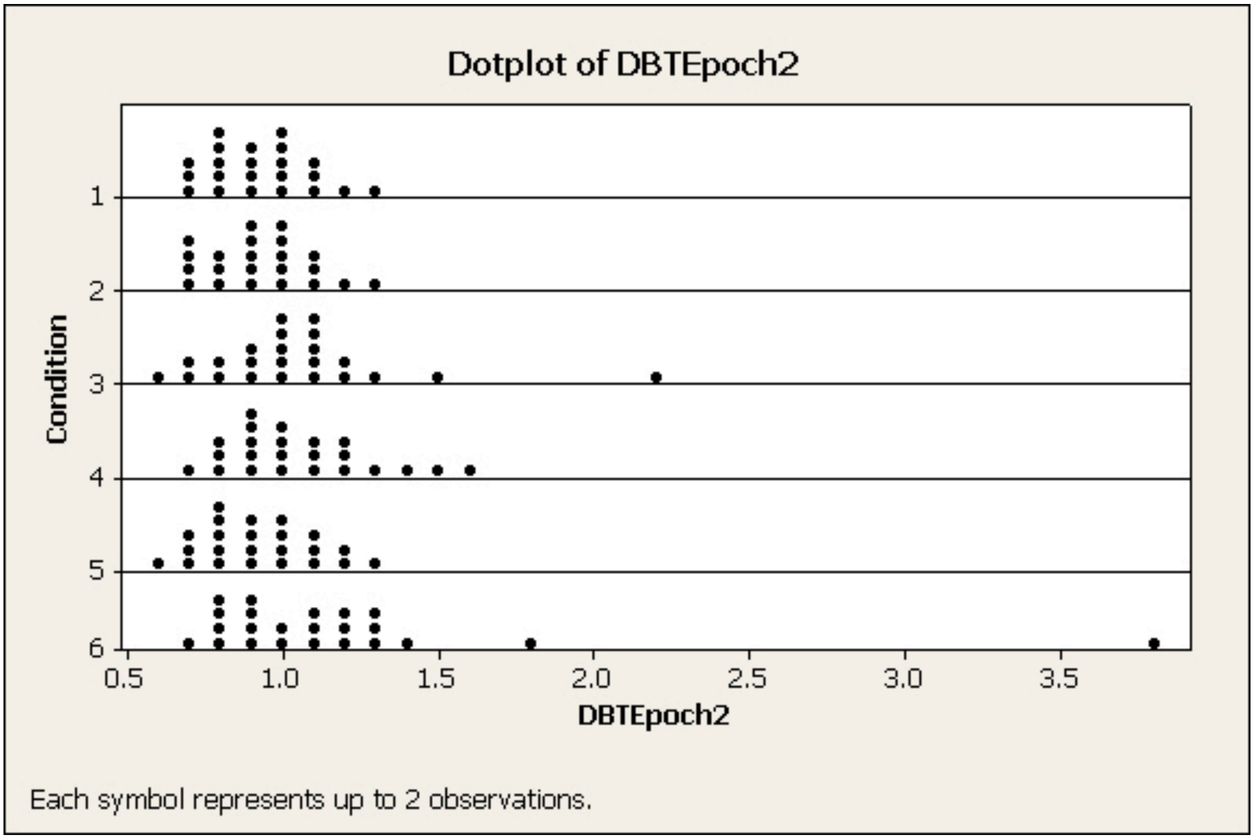


*Figure A15*. Dotplot depicting mean Dwell Before Taskchange (DBT) scores in the second epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

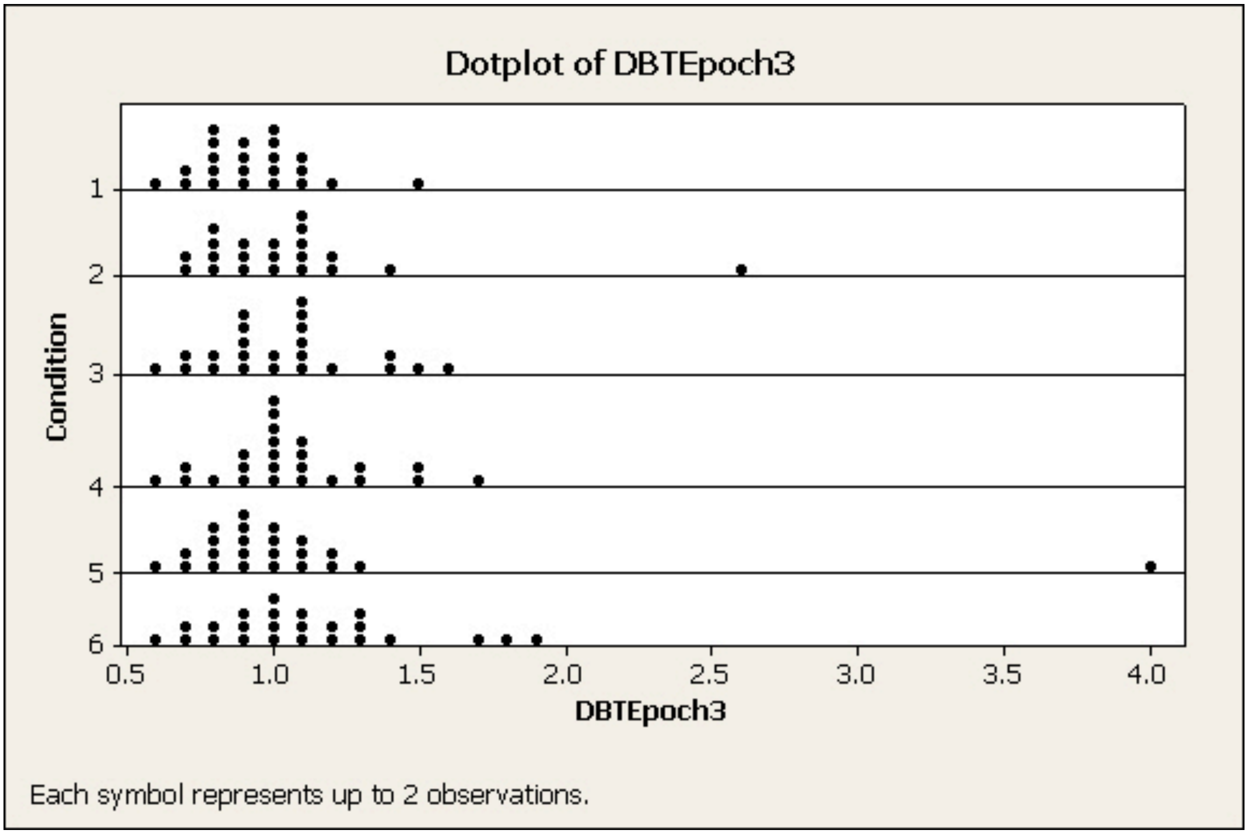


*Figure A16*. Dotplot depicting mean Dwell Before Taskchange (DBT) scores in the third for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

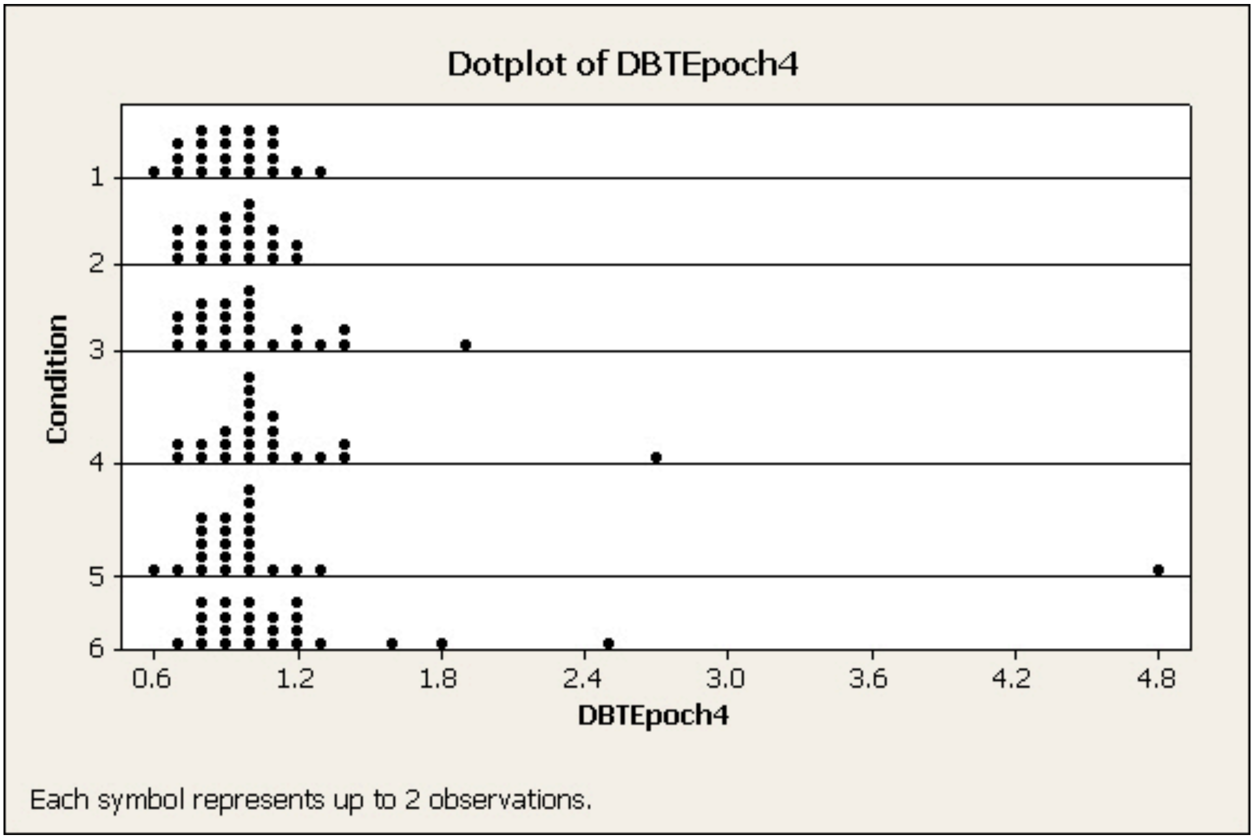


*Figure A17*. Dotplot depicting mean Dwell Before Taskchange (DBT) scores in the fourth epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

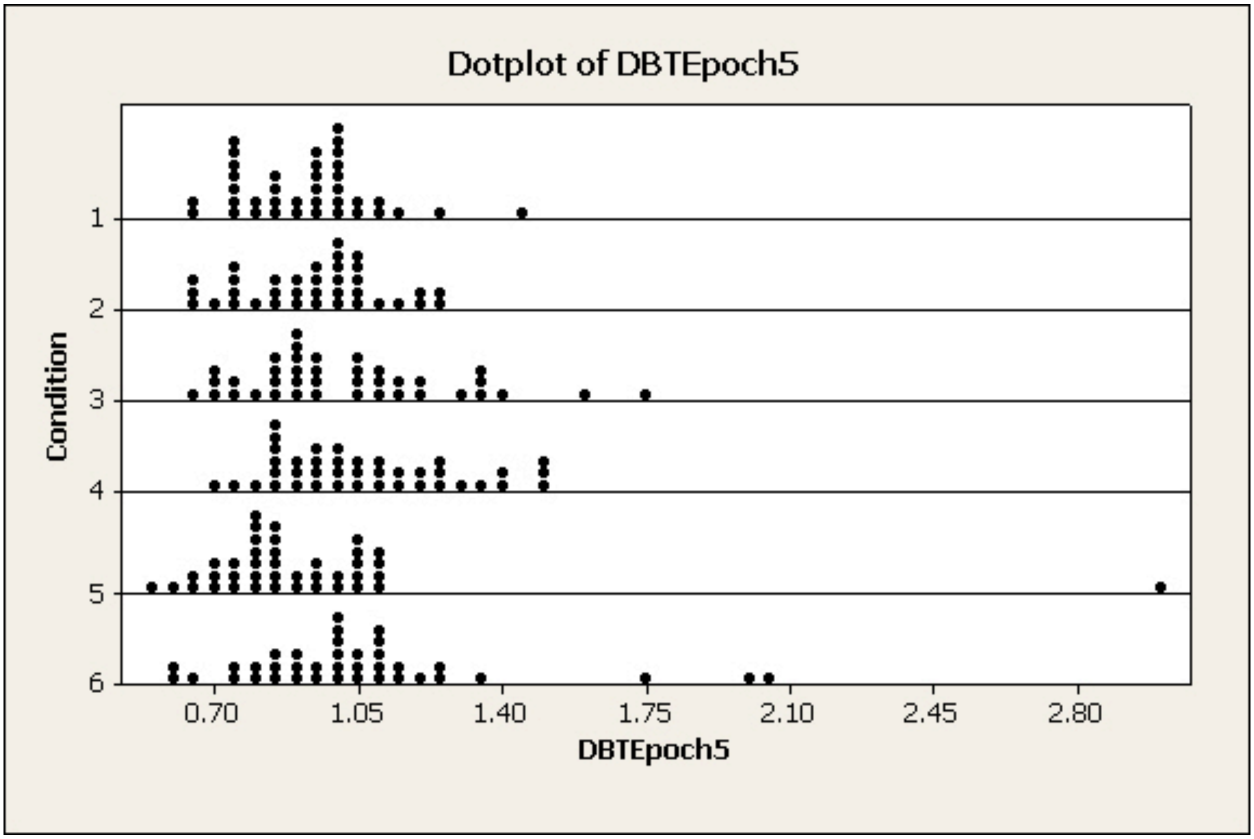


*Figure A18*. Dotplot depicting mean Dwell Before Taskchange (DBT) scores in the fifth epoch for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are time in seconds.

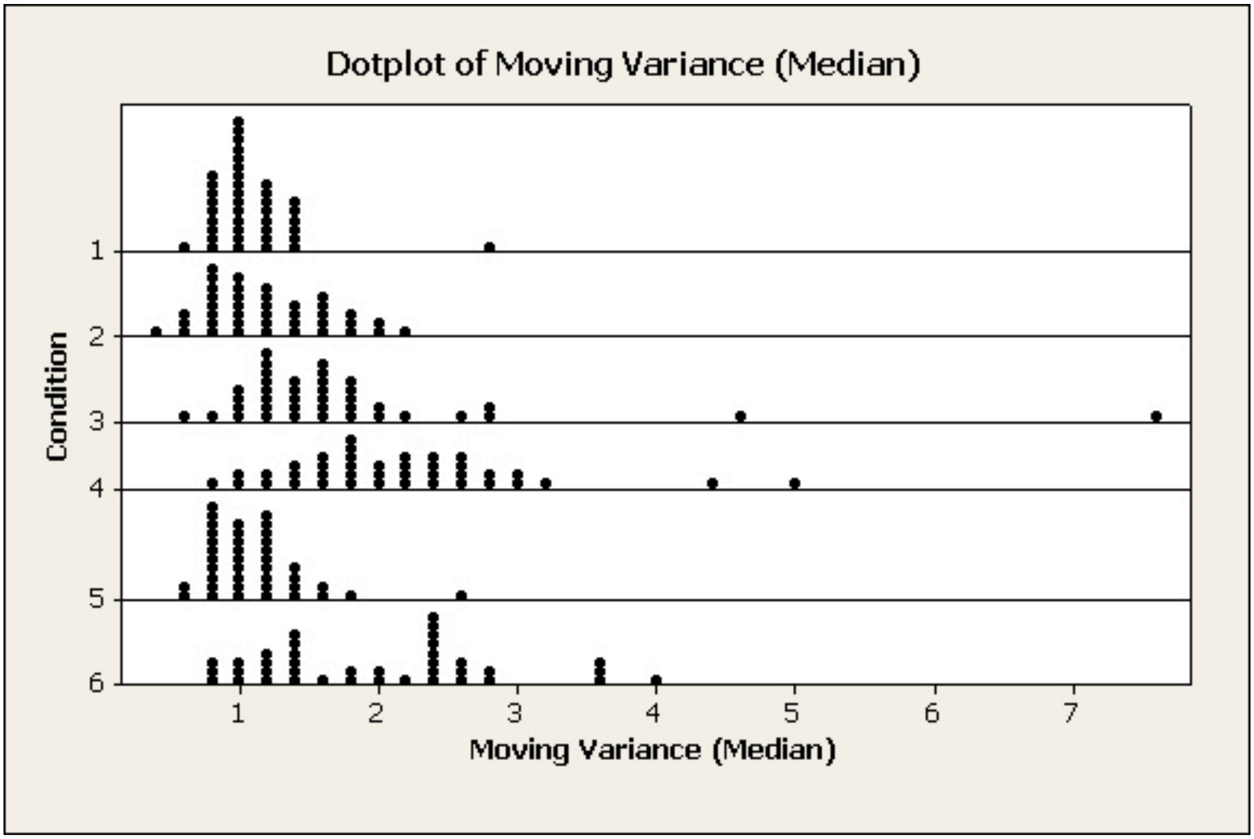


*Figure A19*. Dotplot depicting median Moving Variance scores (all epochs combined) for each of the 6 conditions (1= easy rhythm, easy RT; 2 = difficult rhythm, easy RT; 3 = easy rhythm, difficult RT; 4 = difficult rhythm, difficult RT; 5 = arrhythmic, easy RT; 6 = arrhythmic, difficult RT). Values on the X-axis are Moving Variance scores. Note the greater overall spread in the Moving Variance scores for the difficult response task conditions (3, 4 & 6).

**Appendix B: Institutional Review Board Approval Letter**

R·I·T

**Rochester Institute of Technology**

RIT Institutional Review Board for the
Protection of Human Subjects in Research
141 Lomb Memorial Drive
Rochester, New York 14623-5604
Phone: 585-475-2167
Fax: 585-475-4250
Email: jhrpop@rit.edu

**Form C**
**IRB Decision Form**

**TO:** Daniel Colombo

**FROM:** RIT Institutional Review Board

**DATE:** April 18, 2008

**RE:** Decision of the RIT Institutional Review Board

Project Title – Temporal Awareness in Human Performance

The Institutional Review Board (IRB) has taken the following action on your project named above.

☒ Approved, no greater than minimal risk

Now that your project is approved, you may proceed as you described in the Form A. **Note that this approval is only for a maximum of 12 months; you may conduct research on human subjects only between the date of this letter and 04/18/2009.**

You are required to submit to the IRB any:

- **Proposed** modifications and wait for approval before implementing them,
- Unanticipated risks, and
- Actual injury to human subjects.

Return the Form F, at the end of your human research project or 12 months from the above date. If your project will extend more than 12 months, your project must receive continuing review by the IRB.

Heather Foti
Associate Director, Office of Human Subjects Research

Revised 10-18-06

**Appendix C: Experiment Script**

*Assign each subject a number as they enter the room, beginning with "012", then "013", etc.

1) Informed consent/demographic questionnaire

(Hand subjects the informed consent forms as they enter the room and encourage them to read before signing)

(When completed, give them the background/demographic questionnaire)

2) Intro Script

Hello and thank you for participating in this experiment on mental workload during multi-tasking. We will get started in a few moments with some brief practice runs to familiarize you with the software, but first a word about mental workload. You will be asked how much workload you experience mentally, temporally, in terms of effort, frustration, and in terms of your own performance. You can read along with formal definitions of these factors as I read them aloud.

**Mental Demand:** How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

**Temporal Demand:** How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

**Own Performance:** How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals

**Effort:** How hard did you have to work (mentally and physically) to accomplish your level of performance?

**Frustration:** How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during your task?

(Leave a copy of the definitions with them)

3) Training

Now we'll get started on some practice runs. Please open the folder on your desktop labeled MTTE_5-23. Then click on the application 7-12-TaskSched.exe. Where it says "Subject Number", type in "7". For the field labeled "delay", please enter ".5". Select "Hide Percentage Values". Finally, for the "time" field, enter "2".

Before you run the program, I will explain the nature of the task. You will be in charge of four simultaneous tasks, represented by 4 window panes, in which the critical action you must take is hidden unless you reveal it with mouse cursor activation. There is a half second delay once you reveal the task with your mouse, and it disappears when you switch to another pane. You will see a red progress bar toward the middle of each pane, and your task is to reset this progress bar by entering the provided code as soon as the bar reaches a thin, vertical demarcation denoting the window of opportunity. You may enter the code as soon as the bar reaches the line and the window of opportunity opens, and we encourage you to reset the task as early into the window of opportunity as possible. You must enter the code before the red bar reaches the end, then press the "return/enter" key. This will reset the task in that pane, and you can move on to another. Half of the experimental trials will require the solving of a simple arithmetic problem in lieu of a two digit code. Be sure to monitor the progress of the other tasks, as they may be moving faster or slower than they did last time. This first practice run will require the entering of a two digit code. Any questions?

(Have the subjects begin the first practice trial (7))

(When the first practice trial is complete)

Any questions? Now open the file labeled 7-12-TaskSced.exe again. This next practice trial will test your abilities in the arithmetic condition. Fill in the subject number field with an "8". For the field labeled "delay", please enter ".5", select "hide percentages", and enter "2" for the time field. You may begin whenever you're ready.

(Have the subjects begin the first practice trial)

Good. Now, we will take a brief moment to calibrate your workload.

(Hand out the TLX calibration instruments)

For the particular task in which you just engaged, please select which factor in each pair most contributed to your workload. You are encouraged to review the definitions before proceeding. Any questions?

(Collect Calibration instruments)

Thank you. We will now begin the real trials.

4) Experimental Blocks

* Subjects should be randomly assigned to a given condition (obviously). I usually did this by rolling a six-sided die 6 times until I got 6 different numbers. I can either give you a sequence of random configurations for each participant you recruit, or you may have a better system. I was thinking each participant would have a list of numbers that they should enter into the "Subject Number" field on consecutive trials…probably easiest this way.

In the field labeled "Subject number", please enter the first number on the list you have at your test area beside you. For the other fields, you will enter ".5" for delays, "hide percentages" and "5" for the time. These will be the same for every block of trials, with only the subject number field changing according to your list.

You may begin when you are ready, and please signal to the experimenter when you have completed your block. Once you have completed a block, you will be asked to complete the NASA task load index. This test instrument consists of 5 lines labeled with the same factors you were asked to compare to one another with the calibration. Place a single hashmark on the line for each workload factor, placing the mark further to the right if that figure contributed significantly to workload, or further to the left if it contributed less significantly. There are three such tests per page, so be sure that you complete only one of these after a block of trials.

(Maybe we can label these instruments ahead of time for the subjects)

When you have finished the NASA TLX, you may begin the next block of trials. Feel free to take as much time as you require between each block, and please ask any questions that you may have. When you have completed all 6 experimental blocks, please notify the experimenter so you can complete a brief exit questionnaire.

5) Post-test questionnaire

*This may be handed out to some subjects while others are still testing, so there probably should not be any discussion here.

Thank you.

6) Post-experiment

*The data files should save automatically in the "data" folder in MTTE_5-23, with one plain text csv file for each trial (including the practice). You can rename this data folder according to the participant number and just send me these folders. For example, "013 Data". I think that's all you need to do here; wouldn't hurt to save these in a couple different places…Thanks so much, and please let you know if I should be more or less specific with this document!

**Appendix D: Informed Consent Form**

## INFORMED CONSENT FORM FOR BEHAVIORAL RESEARCH STUDY

**Rochester Institute of Technology**

***Title of Project:*** Temporal awareness in human performance

***Investigators in Charge:***

| | |
|---|---|
| Mr. Daniel Colombo | Dr. Esa M. Rantanen |
| MS Candidate | Associate Professor |
| Dept. of Psychology. | Dept. of Psychology |
| Rochester Inst. of Technology | Rochester Inst. of Technology |
| Tel. (585)944-6459 | 01-3140 Eastman Bldg. |
| Email: dcolombo6@yahoo.com | Tel. (585) 475-4412 |
| | Email: esa.rantanen@rit.edu |


***Explanation of the Project.***

You are being asked to participate in a research study that is looking at the advantages and disadvantages associated with temporal awareness in an abstract supervisory task. The findings from the work will likely be applicable to real-world environments in which temporal components play a key role, such as military, factory or medical settings.

The goal of this work is to evaluate humans' ability to keep track of simultaneous tasks while performing either simple or difficult response tasks.

This study requires you to keep track of four simultaneous tasks, which take the form of panes, viewable one at a time. You will be responsible for two tasks per pane: 1) a timing task, which entails keeping track of a red progress bar and making sure it does not reach the end, and 2) a response task, which will either be the rote copying of a 2-digit code, or simple mental arithmetic. Timely completion of the response task at the right moment of time progression is imperative.

The only risks to you from participating in the experiment is the slight mental workload and fatigue associated with any supervisory or vigilance task.

Results of this research will be used to further enhance our understanding of the role of time in human performance.

***Your rights as a research participant***

We will be happy to answer any questions you have about the study at any time. Mr. Colombo and Prof. Rantanen may be contacted at the telephone numbers and e-mail addresses shown above. If you have questions about your rights as a research subject, you can call collect the Rochester Institute of Technology Institutional Review Board at (585) 475-7673, or e-mail hmfsrs@rit.edu.

No subsequently published results will contain any information that could be associated with individual participants. No information identifying individual subjects will be ever associated with the data collected. All data will be stored and secured only on the investigator's computer after being retrieved from the program.

Your participation is wholly voluntary. Your decision to participate, or to not participate, or to withdraw from the study during the experiment will in no way influence your relationship with the researcher or your professor(s).

You may refuse to participate or may discontinue participation at any time during the project without penalty or loss of benefits to which you are otherwise entitled.

Results of the proposed research will be used to further guide our understanding of temporal awareness.

The results of this research will be submitted to peer-reviewed journal articles and perhaps presented at a human factors-related conference. No information allowing for identification of individual participants will be included in these reports.

***Statement of consent***

Participant:

I agree to participate in this study, which seeks to guide development and testing of human performance in supervisory, time-sensitive environs. I understand the information given to me, and I have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described on this form.

I understand that I am volunteering to participate in this study, that I will be not be compensated for participating apart from the chances of winning a raffle and extra credit in Dr. Herbert or Dr. Rantanen's class (if enrolled), and that I may withdraw from this study at any time without penalty to me.

I certify that I am at least 18 years old.

I understand that I will be given a signed copy of this consent form.

____________________________________ _______________________

Signature Date

Researcher:

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

____________________________________ _______________________

Signature Date

**Appendix E: Post-test Questionnaire**

Post-Test Questionnaire

Subject #:________________________

Do you recall certain conditions as being more ‘mentally taxing’ than others? Which ones, and why?

At any point, did you feel as though you had gotten into a ‘rhythm’ in performing the tasks?

Do you believe rhythm can impart any benefits when performing tasks such as these?

## Appendix F: Background questionnaire

Background Questionnaire

What is your age? ____________________

What is your sex? ______________________

What is your major/ discipline? ____________________

Do you have any music or dance background? If so, how many years?

Do you have trouble clapping along during audience participation segments at concerts? (Y/N)

**Appendix G: 2 X 3 ANOVA Results**

Table G1

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on TFA.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 8.0979 | 8.0979 | 33.15* |
| Rhythm | 2 | 0.559 | 0.2995 | 1.23 |
| ResponseTask | 1 | 35.4579 | 35.4579 | 145.14* |
| Rhythm*ResponseTask | 2 | 3.621 | 1.8105 | 7.41* |
| Error | 233 | 56.9202 | 0.2443 | |
| Total | 239 | | | |

* p = <.01

Table G2

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on DBA.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 12.157 | 12.157 | 21.9* |
| Rhythm | 2 | 7.013 | 3.507 | 6.32* |
| ResponseTask | 1 | 104.667 | 104.667 | 188.52* |
| Rhythm*ResponseTask | 2 | 3.263 | 1.631 | 2.94 |
| Error | 232 | 128.808 | 0.555 | |
| Total | 238 | | | |

* p = <.01

Table G3

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on DBT.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 0.74043 | 0.74043 | 27.18* |
| Rhythm | 2 | 0.05777 | 0.02888 | 1.06 |
| ResponseTask | 1 | 0.84053 | 0.84053 | 30.86* |
| Rhythm*ResponseTask | 2 | 0.0446 | 0.0223 | 0.82 |
| Error | 232 | 6.31984 | 0.02724 | |
| Total | 238 | | | |

* p = <.01

Table G4

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on task performance.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 0.03081 | 0.03081 | 5.24** |
| Rhythm | 2 | 0.00528 | 0.00264 | 0.45 |
| ResponseTask | 1 | 0.66052 | 0.66052 | 112.25* |
| Rhythm*ResponseTask | 2 | 0.0343 | 0.01715 | 2.91 |
| Error | 232 | 1.3652 | 0.00588 | |
| Total | 238 | | | |

* p = <.01

** p = <.05

Table G5

Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on Moving Variance.

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Rhythm | 2 | 4.156 | 2.078 | 2.562 |
| ResponseTask | 1 | 26.424 | 26.424 | 32.574* |
| Rhythm*ResponseTask | 2 | 1.260 | .630 | 0.777 |
| Error | 231 | 113.1554 | 0.4899 | |
| Total | 237 | | | |

* p = <.01

Table G6

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on overall NASA-TLX workload ratings.*

NASA-TLX overall

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 1217.4 | 1217.4 | 3.33 |
| Rhythm | 2 | 10680.9 | 5340.5 | 14.62* |
| ResponseTask | 1 | 24031.7 | 24031.7 | 65.81* |
| Rhythm*ResponseTask | 2 | 7226 | 3613 | 9.89* |
| Error | 231 | 84360.1 | 365.2 | |
| Total | 237 | | | |

* p = <.01

Table G7

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on mental demand.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 2398.5 | 2398.5 | 4.68** |
| Rhythm | 2 | 3563.8 | 1781.9 | 3.47** |
| ResponseTask | 1 | 49530.8 | 49530.8 | 96.54* |
| Rhythm*ResponseTask | 2 | 3757 | 1878.5 | 3.66** |
| Error | 231 | 118511 | 513 | |
| Total | 237 | | | |

* p = <.01

** p = <.05

Table G8

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on temporal demand.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 985 | 985 | 1.72 |
| Rhythm | 2 | 18494.1 | 9247.1 | 16.18* |
| ResponseTask | 1 | 13487.6 | 13487.6 | 23.61* |
| Rhythm*ResponseTask | 2 | 16767.7 | 8383.8 | 14.67* |
| Error | 231 | 131978.9 | 571.3 | |
| Total | 237 | | | |

* p = <.01

Table G9

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on own performance.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 2738.9 | 2738.9 | 4.6** |
| Rhythm | 2 | 4933 | 2466.5 | 4.14** |
| ResponseTask | 1 | 6386.8 | 6386.8 | 10.73* |
| Rhythm*ResponseTask | 2 | 1466.4 | 733.2 | 1.23 |
| Error | 231 | 137498.8 | 595.2 | |
| Total | 237 | | | |

* p = <.01

** p = <.05

Table G10

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on effort.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 2863 | 2863 | 1.81 |
| Rhythm | 2 | 16049 | 8025 | 5.07* |
| ResponseTask | 1 | 44308 | 44308 | 27.99* |
| Rhythm*ResponseTask | 2 | 1496 | 748 | 0.47 |
| Error | 231 | 365656 | 1583 | |
| Total | 237 | | | |

* p = <.01

Table G11

*Table depicting summary results from 2 X 3 ANOVA examining the effects of rhythm and response task difficulty on Frustration.*

| Source | DF | Adj SS | Adj MS | F |
|---|---|---|---|---|
| Years of Dance/Music | 1 | 1267.8 | 1267.8 | 2.56 |
| Rhythm | 2 | 13183.2 | 6591.6 | 13.31* |
| ResponseTask | 1 | 28496 | 28496 | 57.56* |
| Rhythm*ResponseTask | 2 | 10238.9 | 5119.5 | 10.34* |
| Error | 231 | 114364.8 | 495.1 | |
| Total | 237 | | | |

* p = <.01

**Appendix H: One-way ANOVA Results**

Table H1

*ANOVA table depicting the effect of epoch within a given condition on TFA*

| Source | Sum of squares | df | Mean square | F |
|---|---|---|---|---|
| | | Condition 1 | | |
| Between Groups | 4.813 | 4 | 1.203 | 15.072* |
| Within Groups | 15.407 | 193 | 0.08 | |
| Total | 20.22 | 197 | | |
| | | Condition 2 | | |
| Between Groups | 1.378 | 4 | 0.344 | 5.483* |
| Within Groups | 11.684 | 186 | 0.063 | |
| Total | 13.062 | 190 | | |
| | | Condition 3 | | |
| Between Groups | 1.132 | 4 | 0.283 | 2.308 |
| Within Groups | 23.773 | 194 | 0.123 | |
| Total | 24.904 | 198 | | |
| | | Condition 4 | | |
| Between Groups | 23.409 | 4 | 5.852 | 51.993* |
| Within Groups | 21.723 | 193 | 0.113 | |
| Total | 45.132 | 197 | | |
| | | Condition 5 | | |
| Between Groups | 0.555 | 4 | 0.139 | 2.049 |
| Within Groups | 13.138 | 194 | 0.068 | |
| Total | 13.693 | 198 | | |
| | | Condition 6 | | |
| Between Groups | 1.272 | 4 | 0.318 | 2.62** |
| Within Groups | 23.417 | 193 | 0.121 | |
| Total | 24.689 | 197 | | |

* p = <.01

** p = <.05

Table H2

*ANOVA table depicting the effect of condition within a given epoch on TFA.*

| Source | Sum of squares | df | Mean square | F |
|---|---|---|---|---|
| | | Epoch 1 | | |
| Between Groups | 8.869 | 5 | 1.774 | 39.644* |
| Within Groups | 10.425 | 233 | 0.045 | |
| Total | 19.294 | 238 | | |
| | | Epoch 2 | | |
| Between Groups | 13.309 | 5 | 2.662 | 21.247* |
| Within Groups | 29.317 | 234 | 0.125 | |
| Total | 42.626 | 239 | | |
| | | Epoch 3 | | |
| Between Groups | 11.774 | 5 | 2.355 | 18.78* |
| Within Groups | 29.09 | 232 | 0.125 | |
| Total | 40.865 | 237 | | |
| | | Epoch 4 | | |
| Between Groups | 9.228 | 5 | 1.846 | 19.911* |
| Within Groups | 21.411 | 231 | 0.093 | |
| Total | 30.639 | 236 | | |
| | | Epoch 5 | | |
| Between Groups | 15.145 | 5 | 3.029 | 29.682* |
| Within Groups | 22.961 | 225 | 0.102 | |
| Total | 38.106 | 230 | | |

* p = <.01

Table H3

*ANOVA table depicting the effect of epoch within a given condition on Moving Variance.*

| Source | Sum of squares | df | Mean square | F |
|---|---|---|---|---|
| | | Condition 1 | | |
| Between Groups | 1.415 | 4 | 0.354 | 0.343 |
| Within Groups | 198.716 | 193 | 1.03 | |
| Total | 200.131 | 197 | | |
| | | Condition 2 | | |
| Between Groups | 4.193 | 4 | 1.048 | 0.848 |
| Within Groups | 230.034 | 186 | 1.237 | |
| Total | 234.226 | 190 | | |
| | | Condition 3 | | |
| Between Groups | 10.978 | 4 | 2.744 | 1.121 |
| Within Groups | 460.065 | 188 | 2.447 | |
| Total | 471.043 | 192 | | |
| | | Condition 4 | | |
| Between Groups | 8.599 | 4 | 2.15 | 1.254 |
| Within Groups | 332.613 | 194 | 1.715 | |
| Total | 341.212 | 198 | | |
| | | Condition 5 | | |
| Between Groups | 2.207 | 4 | 0.552 | 2.084 |
| Within Groups | 51.361 | 194 | 0.265 | |
| Total | 53.568 | 198 | | |
| | | Condition 6 | | |
| Between Groups | 18.508 | 4 | 4.627 | 3.599* |
| Within Groups | 241.698 | 188 | 1.286 | |
| Total | 260.206 | 192 | | |

* p = <.01

Table H4

*ANOVA table depicting the effect of condition within a given epoch on Moving Variance.*

| Source | Sum of squares | df | Mean square | F |
|---|---|---|---|---|
| | | Epoch 1 | | |
| Between Groups | 19.966 | 5 | 3.993 | 5.579* |
| Within Groups | 137.416 | 192 | 0.716 | |
| Total | 157.382 | 197 | | |
| | | Epoch 2 | | |
| Between Groups | 47.468 | 5 | 9.494 | 5.443* |
| Within Groups | 336.623 | 193 | 1.744 | |
| Total | 384.092 | 198 | | |
| | | Epoch 3 | | |
| Between Groups | 37.977 | 5 | 7.595 | 7.496* |
| Within Groups | 193.524 | 191 | 1.013 | |
| Total | 231.501 | 196 | | |
| | | Epoch 4 | | |
| Between Groups | 40.502 | 5 | 8.1 | 4.68* |
| Within Groups | 327.137 | 189 | 1.731 | |
| Total | 367.639 | 194 | | |
| | | Epoch 5 | | |
| Between Groups | 51.411 | 5 | 10.282 | 5.603* |
| Within Groups | 337.663 | 184 | 1.835 | |
| Total | 389.073 | 189 | | |

* p = <.01

Table H5

*ANOVA table depicting the effect of condition within a given epoch on DBA.*

| Source | Sum of squares | df | Mean square | F |
|---|---|---|---|---|
| | | Epoch 1 | | |
| Between Groups | 118.155 | 5 | 23.631 | 12.365* |
| Within Groups | 370.755 | 194 | 1.911 | |
| Total | 488.909 | 199 | | |
| | | Epoch 2 | | |
| Between Groups | 89.258 | 5 | 17.852 | 18.547* |
| Within Groups | 186.722 | 194 | 0.962 | |
| Total | 275.98 | 199 | | |
| | | Epoch 3 | | |
| Between Groups | 82.571 | 5 | 16.514 | 21.493* |
| Within Groups | 147.521 | 192 | 0.768 | |
| Total | 230.091 | 197 | | |
| | | Epoch 4 | | |
| Between Groups | 108.313 | 5 | 21.663 | 16.922* |
| Within Groups | 244.51 | 191 | 1.28 | |
| Total | 352.823 | 196 | | |
| | | Epoch 5 | | |
| Between Groups | 82.184 | 5 | 16.437 | 26.304* |
| Within Groups | 114.976 | 184 | 0.625 | |
| Total | 197.16 | 189 | | |

T

* p = <.01

Table H6

*ANOVA table depicting the effect of condition within a given epoch on DBT.*

| Source | Sum of squares | df | Mean square | F |
|---|---|---|---|---|
| | | Epoch 1 | | |
| Between Groups | 1.38 | 5 | 0.276 | 5.285* |
| Within Groups | 10.132 | 194 | 0.052 | |
| Total | 11.512 | 199 | | |
| | | Epoch 2 | | |
| Between Groups | 0.704 | 5 | 0.141 | 3.554* |
| Within Groups | 7.69 | 194 | 0.04 | |
| Total | 8.395 | 199 | | |
| | | Epoch 3 | | |
| Between Groups | 0.972 | 5 | 0.194 | 3.489* |
| Within Groups | 10.695 | 192 | 0.056 | |
| Total | 11.666 | 197 | | |
| | | Epoch 4 | | |
| Between Groups | 0.841 | 5 | 0.168 | 2.832** |
| Within Groups | 11.343 | 191 | 0.059 | |
| Total | 12.183 | 196 | | |
| | | Epoch 5 | | |
| Between Groups | 22.468 | 5 | 4.494 | 0.968 |
| Within Groups | 858.751 | 185 | 4.642 | |
| Total | 881.219 | 190 | | |

* p = <.01

** p = <.05

# Appendix I: Means, Standard Deviations and 95% Confidence Intervals for all Timing Measures

| Condition | Timing Measure | Easy rhythm, easy RT | | | | | Difficult rhythm, easy RT | | | | | Easy rhythm, difficult RT | | | | | Difficult rhythm, difficult RT | | | | | Arrhythmic, easy RT | | | | | Arrhythmic, difficult RT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Epoch | | *M* | *sd* | $CI_{95}$ | *Upper Bound* | *Lower Bound* | *M* | *sd* | $CI_{95}$ | *Upper Bound* | *Lower Bound* | *M* | *sd* | $CI_{95}$ | *Upper Bound* | *Lower Bound* | *M* | *sd* | $CI_{95}$ | *Upper Bound* | *Lower Bound* | *M* | *sd* | $CI_{95}$ | *Upper Bound* | *Lower Bound* | *M* | *sd* | $CI_{95}$ | *Upper Bound* | *Lower Bound* |
| 1 | TFA | 2.72 | 1.02 | 0.32 | 3.04 | 2.40 | 2.28 | 1.18 | 0.37 | 2.65 | 1.91 | 6.5 | 4.35 | 1.35 | 7.85 | 5.15 | 5.44 | 4.35 | 1.35 | 6.79 | 4.09 | 1.58 | 0.5 | 0.15 | 1.73 | 1.43 | 2.61 | 2.16 | 0.67 | 3.28 | 1.94 |
| | DBA | 1.68 | 0.5 | 0.15 | 1.83 | 1.53 | 1.94 | 0.63 | 0.2 | 2.14 | 1.74 | 2.86 | 0.88 | 0.27 | 3.13 | 2.59 | 3.28 | 1.28 | 0.4 | 3.68 | 2.88 | 2.29 | 0.83 | 0.26 | 2.55 | 2.03 | 3.75 | 1.71 | 0.53 | 4.28 | 3.22 |
| | DBT | 0.9 | 0.14 | 0.04 | 0.94 | 0.86 | 0.93 | 0.16 | 0.05 | 0.98 | 0.88 | 1.03 | 0.23 | 0.07 | 1.10 | 0.96 | 1.1 | 0.33 | 0.1 | 1.20 | 1.00 | 0.86 | 0.17 | 0.05 | 0.91 | 0.81 | 1.04 | 0.25 | 0.08 | 1.12 | 0.96 |
| | Moving Var | 1.17 | 0.86 | 0.27 | 1.44 | 0.90 | 1.24 | 0.9 | 0.28 | 1.52 | 0.96 | 1.43 | 0.67 | 0.21 | 1.64 | 1.22 | 1.96 | 1.14 | 0.35 | 2.31 | 1.61 | 1.01 | 0.36 | 0.11 | 1.12 | 0.90 | 1.65 | 0.55 | 0.17 | 1.82 | 1.48 |
| 2 | TFA | 1.34 | 1 | 0.31 | 1.65 | 1.03 | 1.36 | 0.78 | 0.24 | 1.60 | 1.12 | 6.59 | 8.4 | 2.6 | 9.19 | 3.99 | 5.99 | 8.05 | 2.49 | 8.48 | 3.50 | 2.12 | 1.46 | 0.45 | 2.57 | 1.67 | 4.01 | 2.61 | 0.81 | 4.82 | 3.20 |
| | DBA | 1.78 | 0.38 | 0.12 | 1.90 | 1.66 | 1.99 | 0.57 | 0.18 | 2.17 | 1.81 | 2.81 | 0.94 | 0.29 | 3.10 | 2.52 | 3.29 | 1.21 | 0.37 | 3.66 | 2.92 | 1.71 | 0.38 | 0.12 | 1.83 | 1.59 | 3.21 | 1.07 | 0.33 | 3.54 | 2.88 |
| | DBT | 0.92 | 0.15 | 0.05 | 0.97 | 0.87 | 0.93 | 0.16 | 0.05 | 0.98 | 0.88 | 1 | 0.2 | 0.06 | 1.06 | 0.94 | 1.05 | 0.23 | 0.07 | 1.12 | 0.98 | 0.91 | 0.17 | 0.05 | 0.96 | 0.86 | 1.07 | 0.25 | 0.08 | 1.15 | 0.99 |
| | Moving Var | 1.43 | 1.45 | 0.45 | 1.88 | 0.98 | 1.48 | 1.12 | 0.35 | 1.83 | 1.13 | 2.02 | 1.59 | 0.49 | 2.51 | 1.53 | 2.6 | 1.55 | 0.48 | 3.08 | 2.12 | 1.23 | 0.59 | 0.18 | 1.41 | 1.05 | 2.22 | 0.69 | 0.21 | 2.43 | 2.01 |
| 3 | TFA | 1.29 | 0.85 | 0.26 | 1.55 | 1.03 | 1.42 | 0.86 | 0.27 | 1.69 | 1.15 | 5.72 | 7.15 | 2.22 | 7.94 | 3.50 | 5.12 | 5.08 | 1.57 | 6.69 | 3.55 | 1.58 | 1.12 | 0.35 | 1.93 | 1.23 | 3.84 | 3.25 | 1.01 | 4.85 | 2.83 |
| | DBA | 1.85 | 0.49 | 0.15 | 2.00 | 1.70 | 2.11 | 0.53 | 0.16 | 2.27 | 1.95 | 2.75 | 0.76 | 0.24 | 2.99 | 2.51 | 3.27 | 1.06 | 0.33 | 3.60 | 2.94 | 1.86 | 0.48 | 0.15 | 2.01 | 1.71 | 3.84 | 1.77 | 0.55 | 4.39 | 3.29 |
| | DBT | 0.93 | 0.17 | 0.05 | 0.98 | 0.88 | 0.97 | 0.18 | 0.06 | 1.03 | 0.91 | 1.01 | 0.22 | 0.07 | 1.08 | 0.94 | 1.05 | 0.22 | 0.07 | 1.12 | 0.98 | 0.93 | 0.16 | 0.05 | 0.98 | 0.88 | 1.07 | 0.29 | 0.09 | 1.16 | 0.98 |
| | Moving Var | 1.25 | 0.61 | 0.19 | 1.44 | 1.06 | 1.66 | 1.08 | 0.33 | 1.99 | 1.33 | 1.79 | 1.25 | 0.39 | 2.18 | 1.40 | 2.33 | 1.14 | 0.35 | 2.68 | 1.98 | 1.25 | 0.51 | 0.16 | 1.41 | 1.09 | 2.46 | 1.08 | 0.33 | 2.79 | 2.13 |
| 4 | TFA | 1.67 | 0.95 | 0.29 | 1.96 | 1.38 | 1.65 | 0.75 | 0.23 | 1.88 | 1.42 | 6.57 | 5.69 | 1.76 | 8.33 | 4.81 | 4.6 | 5.69 | 1.76 | 6.36 | 2.84 | 1.63 | 0.86 | 0.27 | 1.90 | 1.36 | 4.27 | 4.58 | 1.42 | 5.69 | 2.85 |
| | DBA | 1.7 | 0.43 | 0.13 | 1.83 | 1.57 | 2.06 | 0.72 | 0.22 | 2.28 | 1.84 | 2.92 | 0.93 | 0.29 | 3.21 | 2.63 | 3.28 | 1.04 | 0.32 | 3.60 | 2.96 | 1.77 | 0.46 | 0.14 | 1.91 | 1.63 | 3.48 | 1.17 | 0.36 | 3.84 | 3.12 |
| | DBT | 0.92 | 0.17 | 0.05 | 0.97 | 0.87 | 0.95 | 0.14 | 0.04 | 0.99 | 0.91 | 0.98 | 0.21 | 0.07 | 1.05 | 0.91 | 1.01 | 0.18 | 0.06 | 1.07 | 0.95 | 0.93 | 0.15 | 0.05 | 0.98 | 0.88 | 1.04 | 0.15 | 0.05 | 1.09 | 0.99 |
| | Moving Var | 1.3 | 1.02 | 0.32 | 1.62 | 0.98 | 1.62 | 1.27 | 0.39 | 2.01 | 1.23 | 1.97 | 1.92 | 0.6 | 2.57 | 1.37 | 2.3 | 1.16 | 0.36 | 2.66 | 1.94 | 1.17 | 0.52 | 0.16 | 1.33 | 1.01 | 2.54 | 1.35 | 0.42 | 2.96 | 2.12 |
| 5 | TFA | 1.33 | 1.11 | 0.34 | 1.67 | 0.99 | 1.8 | 1.25 | 0.39 | 2.19 | 1.41 | 7.36 | 6.71 | 2.08 | 9.44 | 5.28 | 5.69 | 6.59 | 2.04 | 7.73 | 3.65 | 1.81 | 0.67 | 0.21 | 2.02 | 1.60 | 4.21 | 3.66 | 1.13 | 5.34 | 3.08 |
| | DBA | 1.79 | 0.5 | 0.15 | 1.94 | 1.64 | 2.05 | 0.68 | 0.21 | 2.26 | 1.84 | 2.91 | 0.94 | 0.29 | 3.20 | 2.62 | 3.17 | 0.93 | 0.29 | 3.46 | 2.88 | 1.64 | 0.39 | 0.12 | 1.76 | 1.52 | 3.2 | 1.08 | 0.33 | 3.53 | 2.87 |
| | DBT | 0.92 | 0.16 | 0.05 | 0.97 | 0.87 | 0.94 | 0.16 | 0.05 | 0.99 | 0.89 | 1.02 | 0.25 | 0.08 | 1.10 | 0.94 | 1.06 | 0.22 | 0.07 | 1.13 | 0.99 | 0.87 | 0.15 | 0.05 | 0.92 | 0.82 | 1.04 | 0.31 | 0.1 | 1.14 | 0.94 |
| | Moving Var | 1.25 | 0.92 | 0.29 | 1.54 | 0.96 | 1.53 | 1.15 | 0.36 | 1.89 | 1.17 | 2.11 | 1.98 | 0.61 | 2.72 | 1.50 | 2.38 | 1.47 | 0.46 | 2.84 | 1.92 | 1.06 | 0.33 | 0.1 | 1.16 | 0.96 | 2.51 | 1.33 | 0.41 | 2.92 | 2.10 |

## Appendix J: Summary Results from 2 X 3 ANOVAs Performed on Epoch Aggregates

Table M1

*Summary of 2 X 3 ANOVA results for the timing measures TFA, DBA, DBT and Moving Variance. Columns represent the first 3 epochs of performance (pre "trick"), the last 2 epochs of performance (post "trick") and overall.*

| Timing measure and factor | | Epochs 1-3 | | Epochs 4 & 5 | | Overall | |
|---|---|---|---|---|---|---|---|
| | | F-statistic | p-value | F-statistic | p-value | F-statistic | p-value |
| Time to first action (TFA) | Rhythm | 0.93 | 0.396 | 1.18 | 0.308 | 1.23 | 0.295 |
| | Response Task | 120.64 | <.001 | 141.33 | <.001 | 145.14 | <.001 |
| | Rhythm*Response task | 7.13 | 0.001 | 12.45 | <.001 | 7.41 | 0.001 |
| Dwell before action (DBA) | Rhythm | 7.57 | 0.001 | 3.64 | 0.028 | 6.32 | 0.002 |
| | Response Task | 150.55 | <.001 | 191.76 | <.001 | 188.52 | <.001 |
| | Rhythm*Response task | 2.76 | 0.065 | 2.75 | 0.066 | 2.94 | 0.055 |
| Dwell before task-change (DBT) | Rhythm | 1.02 | 0.361 | 0.91 | 0.406 | 1.06 | 0.348 |
| | Response Task | 33.52 | <.001 | 18.29 | <.001 | 30.86 | <.001 |
| | Rhythm*Response task | 0.7 | 0.498 | 0.8 | 0.452 | 0.82 | 0.442 |
| Moving Variance | Rhythm | 3.37 | 0.036 | 2.32 | 0.1 | 2.56 | 0.08 |
| | Response Task | 28.96 | <.001 | 23.68 | <.001 | 32.57 | <.001 |
| | Rhythm*Response task | 1.171 | 0.312 | 0.004 | 0.996 | 0.777 | 0.461 |

## Appendix K: NASA-TLX Workload Factor Definitions

***NASA-TLX Definitions (Hart & Staveland, 1988)***

- **Mental Demand:** How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
- **Temporal Demand:** How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
- **Own Performance:** How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals
- **Effort:** How hard did you have to work (mentally and physically) to accomplish your level of performance?
- **Frustration:** How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during your task?