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EFFECTS OF FOREPERIOD REGULARITY AND MUSCLE SIZE ON FRACTIONATED REATION TIME

by

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DISSERTATION

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Advisor Date

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DEDICATION

I dedicate this work to my family and friends who continually supported not only the academic, but also my personal journey to this point. Specifically, I would like to express my sincere appreciation to my mentors, Dr. Lai and Dr. Engels, for their unwavering belief in my ability to succeed. Their tenacious work ethic and intellectual curiosity made my time at WSU one of significant personal and creative growth. I consider them to not only be great mentors, but also friends. I firmly believe my life would lack the quality I have today had I never met them, and for that, I am forever grateful.

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CHAPTER 1: INTRODUCTION

Successful human functioning is reliant on how efficiently a person is able to utilize their senses to inform them about their environment, simply known as human information processing. Reaction time (RT) has been well studied as a way to indirectly measure this processing, and as a consequence, several theories have been developed in the attempt to explain the speed with which the mental events occur and lead to a desired action. As a result of these theories, much is now known about how the central nervous system processes effect reaction time. However, these theories have neglected to explain the processing that happens in the peripheral nervous system, and as such, very little is known about how reaction time is affected by the peripheral processing that occurs in order to prepare the musculature for a physical response. There is a current lack of understanding regarding the independent variables that have an effect over the peripheral preparation of movement.

Helmholtz (1850) introduced the RT experiment as a way to measure the speed of nerve conduction in frogs. Though it wasn’t until the work of the Dutch physiologist F.C. Donders, who utilized RT experiments to study mental processes, that investigating RT came into mainstream research. Donders (1868/1969) was the first to measure the time required for the processing of certain mental stages by manipulating the conditions of a reaction time task, which he termed the subtractive method. The notion was that the time between the stimulus and response was set in a queue of successive, non-overlapping stages, which could be singled out by way of subtracting the mean reaction times from two different tasks. Though the subtractive method wasn’t without flaws, Donders early attempts at measuring the duration of stimulus discrimination and response selection paved the way for other experimental techniques for investigating the central processing stages (e.g. the additive-factor method (Sternberg, 1969), the discrete-stage model (Taylor, 1976), and the cascade model (McClelland, 1979).

Several authors (Sanders, 1980; Schmidt & Lee, 2005; Massaro, 1989; Posner, 1978) have explained motor behavior through its neurological correlates using a variety of information processing models. Though these models vary in the number of stages and how they are defined, they all offer the same basic premise. Schmidt & Lee (2005) provides a detailed and possibly least cluttered version of the information-processing model (see Figure 1), which includes three sequential stages that operate neurologically to process information leading to a desired action: (1) stimulus identification, (2) response selection, and (3) response programming.

Figure 1. Three stages of information processing model.

Each of the stages, given the separate processing, will consume a certain amount of time. The combination of these stages accounts for most of the latency experienced in reaction time, though other neuromotor factors of the electromechanical delay, which are responsible for force production in the responding muscle, are additive as well.

The experimental methodology commonly used to study information-processing time is called chronometric measurement (Posner, 1978). The rationale for using RT to measure information-processing time is that it serves as an index of psychological function, as demonstrated by the interval between the presentation of a stimulus and the beginning of the response. Specific environmental factors, such as stimulus intensity or clarity, are related to the particular time requirements of stimulus identification, while having no timing effect on the response programming stage. Through manipulation of various environmental factors, the measurement of RT indirectly allows us to observe how each factor impacts central processing time. Considering the simple stages of information processing in Schmidt's model (2005), the effect of a few known stimulus properties can be addressed.

Stimulus identification is the first stage, and it is here that the environment communicates with the person. The stage of stimulus identification involves detection of the stimulus and the information provided from the stimulus must then be identified as a part of a pattern. Some of the stimulus properties known to affect the time latency at this stage are stimulus clarity, intensity, modality (Woodworth, 1954), and stimulus pattern complexity (Schmidt & Lee, 2005). These factors suggest that we will decrease RT if the stimulus is clear, sharp, and well learned.

The response-selection stage utilizes the information that has been analyzed in the previous stage to make an appropriate decision as to what motor behavior should be chosen. Though, this decision is not always straightforward and often requires more processing time as the number of alternative responses grows. This is referred to as choice reaction time, whereas based on the stimulus provided, the person must choose the correct response from a predetermined set, and as the number of stimulus-response (S-R) alternatives increases, so does the time required to make the decision. This increase in RT latency observed with an increase in S-R alternatives was popularized by two different people at about the same time: Hick (1952) and Hyman (1953). Hick and Hyman discovered that choice RT appeared to increase by a nearly constant amount (about 150 ms) every time the number of S-R alternatives doubled. This formal relation is known as Hick’s Law, which states that choice RT is linearly related to the logarithm to the base 2 (Log_2) of the number of S-R alternatives. The importance of this relationship is that the time required to make a decision about a response is linearly related to the amount of information that must be processes in arriving at that decision (Schmidt & Lee, 2005).

Another factor known to affect response-selection time is S-R compatibility, a term coined by Small (1990), which is the extent of the association between (or the degree of 'naturalness' between) a stimulus (or set of stimuli) and the response (or set of responses, called the S-R ensemble). One example of S-R compatibility operating in a 'natural' way would be responding to a visual stimulus presented on the right side of a monitor by using the right hand to depress a button located at their right side, this agreeableness will decrease RT. However, if the arrangement were mixed (pairing a left side stimulus with a right side response), the RT will increase, this is known as the Simon effect (Simon & Rudell, 1967), demonstrating the additional time required to process the environmental information and choose correctly in a S-R incompatible task.

Response programming is the final stage of information processing in Schmidt's model, which allows the person to communicate with their environment. Here, the organization and initiation of the observable behavior is programed. That is, some abstract program of action must be retrieved from memory, the program must be prepared for activation, the relevant portions of the motor system need to be readied for the program (called feedforward), and that the movement be initiated (Schmidt & Lee, 2005). Inherent to the motor program is the notion of effector-independence, wherein the motor program will proceed in the same relative fashion regardless of the muscles and joints involved in the action.

Some of the factors shown to have an effect on response programming time that are included in movement complexity are, number of movement parts, movement accuracy, movement duration, and response-response (R-R) compatibility. Henry and Rogers (1960) were the first to study movement complexity, finding that as the complexity of the pending action increased, the motor program would require a progressively longer time to begin, they called this the memory drum theory of neuromotor reaction. Specifically, that the brain is able to control coordinative voluntary acts by subconsciously drawing from a motor memory storage drum mechanism. Their original idea was that as the complexity of the movement to be made increased, so would the time necessary to coordinate the involved brain centers, and thus increase the processing time required to initiate the physical action. To test this hypothesis, they developed three movement tasks: A, finger lift; B, finger lift and grasp a ball; C, finger lift, backhand a ball, press a switch and then grasp a ball. The number of movement parts doubled for each task with A, B, and C requiring one, two, and four movements, respectively. Besides the increase in movement parts, task B and C also involved an accuracy component, which may have further increased the reaction time latency in their study (Anson, 1982; Sidaway, Sekiya, & Fairweather, 1995).

Although the search to define what makes a movement more complex has drawn a considerable research attention (Fischman, 1984; Fitts & Peterson, 1964; Christina, 1992; Henry, 1980; Klapp, 1977, 1996; Sternberg, Monsell, Knoll, & Wright, 1978; Franks, Nagelkerke, Ketelaars, & van Donkelaar, 1998), the question of response-response (R-R) compatibility has only been examined on a limited basis (Clark, 1982; Heuer, 1982; Kornblum, 1965; Miller, 1982; Shulman & McConkie, 1973). R-R compatibility refers to the relationship that responses share, and how manipulation of this relationship, either congruent or incongruent, affects each other while performing a task simultaneously. The first to investigate the R-R compatibility was Kornblum in 1965, where he measured the RT for the index and middle fingers of both hands. Kornblum (1965) demonstrated that the RT for a particular finger is dependent on the choice alternative with which it is paired. It was found that choosing between contralateral fingers was significantly faster than choosing between ipsilateral fingers. Kornblum suggested that his findings supported the hypothesis that much of the time consumed in an RT task is a result of inhibitory processes for competing incorrect response alternatives.

The use of RT latency to predict the efficiency of response programming under various conditions allows an indirect way to account for the processing responsible for the coordination of planned motor behavior. The factors that have been explored for their effects on response programming include movement duration (Klapp, 1975; Klapp & Erwin, 1976; Klapp & Wyatt, 1976; Ivry, 1986; Zelaznik, Shapiro, & Carter, 1982; Zelaznik & Hahn, 1985), movement timing (Ivry, 1986; Zelaznik, Shapiro, & Carter, 1982; Zelaznik & Hahn, 1985; Baba & Marteniuk, 1983), movement direction (Fischman, 1984; Larish & Frekany, 1985; Rosenbaum, 1980), movement force (Ivry, 1986; Baba & Marteniuk, 1983; Glencross, 1972; Lagasse & Hayes, 1973), extent of movement (Larish & Frekany, 1985; Rosenbaum, 1980; Lagasse & Hayes, 1973), side of body controlled (Rosenbaum, 1980; Annett & Annett, 1979; Nakamura, Taniguchi, & Oshima, 1976), and number of movement parts (Henry & Rogers, 1960; Zelaznik, Shapiro, & Carter, 1982; Fischman, 1984; Jeannerod, 1984; Light & Spirduso, 1990).

Though it is only possible to indirectly account for processing time, the time spent in central verses peripheral processing can more objectively be determined. The technique of fractionating reaction time (FRT) was developed by Weiss (1965) and provided a more definitive way to categorize the variables that effect central processing time (PMT) or peripheral processing time (MT). Even though the work by Henry & Rogers (1960) was published five years prior to the development of FRT, more recent work has been conducted to determine the validity of their memory drum theory while incorporating the FRT technique (Christina & Rose, 1985; Anson, 1982, 1989; Fischman, 1984). Though, the research involving anatomical or kinetic investigations employing FRT remains scant.

Anatomical unit (whole arm vs. finger) has been investigated (Anson, 1982), though differences in muscle size has not been specifically addressed in the literature, possibly because of the quest to determine a true definition of complexity (Henry & Rogers, 1960; Henry, 1980; Christina, 1992) and the factors that have an effect on central processing time. In the search for this definition, it was surmised (Anson, 1982) that some anatomical (number or size of limb segments involved) and physiological (muscle architecture, fiber type) variables, referred to as response-specific variables (Klapp, 1978, 1980; Klapp, Wyatt, & Lingo, 1974), could also have an effect on reaction time. Here, response-specific refers to variables of a peripheral, non-central programming nature, and the limited amount of research pertaining to these variables warrants further investigation to determine the physical factors that may have an effect on the peripheral processing necessary for movement preparation.

More specifically, two researchers (Fischman, 1984; Anson, 1989) have yielded greater support for the variables thought to have an effect on either central or peripheral processing. Employing the FRT method, Fischman (1984) successfully replicated the work by Henry & Rogers (1960) and was able to clearly demonstrate that reaction time increased linearly as the number of moving parts in the response increased, and concluded that the increased latency was of central origin. He reasoned that the greater central processing time was likely due to the complexity of the response requiring more programming time. On the other hand, Anson (1989) investigated what he believed to be a peripheral non-programming variable; moment of inertia. He found that within the same anatomical unit, reaction time increased significantly with an increase in inertia. This was found by comparing weighted vs. unweighted movements with either a 176g weight strapped to the wrist during elbow flexion (experiment one) or a 145g weighted sleeve placed over the index finger during finger extension (experiment two). Reaction time was significantly longer in both weighted conditions with motor time being responsible for the increase in latency and premotor time remaining virtually unchanged. He concluded that the greater delay in motor time may have been caused by the muscle requiring more time to generate an appropriate torque to initiate the movement of the weighted segment.

There are, however, some reasonable concerns with these studies. First, the findings by Fischman (1984) and Anson (1989) have not been replicated unequivocally. This is possibly due to the relatively small number of researchers utilizing FRT, and to a greater extent, due to the differences in experimental design. Second, the data collection equipment used in these studies lacked the precision that currently is available. For example, the equipment used in those studies, as in others of the same time, was typically a keyboard or some metal-to-metal type of contact that would start and stop the reaction time clock. This is problematic because of an issue known as debouncing, which is the tendency of any two metal contacts to generate multiple signals as the contacts close and open. Not only is this additive to the total measurement value, but also inconsistently additive as the number of signals sent during each key-press (response) can vary. Third, both Fischman (1984) and Anson (1989) neglected to assess the effect of practice as each researcher only analyzed participant performance during the final block of trials. Lastly, Fischman (1984) did not manipulate the foreperiod.

Maintaining a regular foreperiod will permit the participant to quickly learn the temporal pattern, thereby allowing the participant to anticipate with a high degree of accuracy. The participant can essentially prepare the last two stages of the information processing model before the stimulus onset and keep it at-the-ready in working memory. The participant could therefore decrease their reaction time by implementing the program as soon as the stimulus was detected, consequently disturbing the theoretical sequence of information processing and potentially masking a complexity effect.

Fischman (1984) made the argument that the linear increase in response latency was matched to the increase in the number of moving parts in the response, and that this was evidence for a complexity variable in central processing because of the greater programming time required to initiate a response. I disagree with this conclusion because the regular foreperiod would allow the participant to upload the motor program to working memory in advance of the stimulus onset, thereby making the process less complex. I believe the true cause of the increase in central processing time was because of an increase in the amount of data that had to be downloaded to initiate the response. For example, opening a large PDF document (20 MB) would take considerably longer to view than opening a small PDF document (1 MB), simply because there is more information and not that it is more difficult to process. Therefore, providing an irregular foreperiod in a reaction time task is a more deliberate way to affect central processing time, as no reliable anticipatory action can be scheduled and no stage-skipping can occur.

On the other hand, Anson (1989) did manipulate the foreperiod, but only in his second experiment. Surprisingly, he did not analyze the irregular foreperiod as an independent variable and possibly for this reason the results showed no significant difference in premotor time. Further, he manipulated the inertia only in the same anatomical unit in both of his experiments, never addressing the potential difference among the anatomical units of different size, or more specifically, from different size effectors (biceps brachii vs. extensor indicis).

Interestingly, these concepts have been broadly ignored, with the exception of a focus on force (Klemmer, 1957b; Nagasaki, Aoki, & Nakamura, 1983; Haagh, Spijkers, van den Boogaart,

& van Boxtel, 1987; Glencross, 1973; Newell & Carlton, 1985), although the results from these studies are equivocal. This imbalance in the FRT literature therefore necessitates further inquiry. Not only does this fractionation technique provide more precise information about the central action planning process, it permits the ability to observe the under-emphasized peripheral component, which clearly warrants greater attention.

Scope and Significance

Interestingly, the peripheral processes that affect reaction time, which are indicative of the movement preparation, have largely been ignored and require further investigation. Therefore, the scope of this dissertation was an evaluation of the independent variables that are thought to have an effect on the components of fractionated reaction time, as well as to introduce an innovative data acquisition technique to the scientific community.

The evaluation of the independent variables was two-fold. First, was to evaluate the effect of a regular and irregular foreperiod paradigm, alternated by block, on fractionated simple reaction time during the initiation of rapid thumb opposition. Second, was to determine the effect of a small and large muscle size paradigm, alternating by block, on fractionated simple reaction time, using a regular foreperiod during the initiation of rapid thumb opposition or elbow extension. Fractionating reaction time into its central and peripheral components has provided scientific evidence for how human motor control processes are affected by foreperiod regularity, sequence order of the foreperiod, muscle size, and sex. More specifically, the results from this study have answered the following questions (1) If alternating the foreperiod by block has an effect on reaction time, is the effect observed in PMT, MT, or both? (2) If alternating muscle size by block with a regular foreperiod has an effect on reaction time, will the effect be observed in PMT, MT, or both?

In order to answer these questions and enhance cohesion between the experimental design and task, I created three simple reaction time programs utilizing the E-Prime 2.0 software. Additionally, I have integrated the BIOPAC MP100 data acquisition system and Acq*Knowledge* software with the millisecond timing precision of the E-Prime 2.0 Psychological Research Software. This refinement in temporal syncing of the central and peripheral dependent variables not only increases the accuracy in detecting the EMG onset, but also decreases human error in the fractionation of reaction time.

This is of benefit to the scientific community, as it, to this authors' knowledge, was the first time that E-Prime 2.0 has been coded to fully integrate with the BIOPAC MP100 System. This integration enhanced the quality and reliability of the data collected, accurate to the millisecond, which increases the potential to elucidate the locus of change within the components of fractionated reaction time. Studying fractionated reaction time is important because it allows the researcher to better understand not just the central, but also the peripheral processes that lead to and have an effect on movement.

The results from this study may have important clinical significance, such as leading to new non-invasive diagnostic testing for information processing disturbances caused by neurological disorders such as Parkinson's disease or stroke. Further, the findings of this study may result in advanced coaching or training protocols targeted at improving athletic performance by decreasing response time, fatigue, and risk of injury.

Hypotheses

Experiment One

H_1: Reaction time will decrease significantly with practice across blocks ($p < 0.05$).

H_2: Reaction time will increase significantly in the irregular foreperiod blocks compared to the regular foreperiod blocks ($p < 0.05$).

H_3: PMT will increase significantly in the irregular foreperiod blocks compared to the regular foreperiod blocks ($p < 0.05$).

H_4: MT will not be significantly different between irregular and regular foreperiods across blocks ($p > 0.05$).

Experiment Two

H_1: Reaction time will decrease significantly with practice across blocks ($p < 0.05$).

H_2: Reaction time will increase significantly in the lateral triceps brachii blocks compared to the abductor pollicis brevis blocks ($p < 0.05$).

H_3: PMT will not be significantly different across blocks between the lateral triceps brachii and abductor pollicis brevis ($p > 0.05$).

H_4: MT will increase significantly in the lateral triceps brachii blocks compared to the abductor pollicis brevis blocks ($p < 0.05$).

H_5: Relative-timing of FRT components will not be significantly different between the lateral triceps brachii and abductor pollicis brevis ($p > 0.05$).

Assumptions

- Participants were focused on the task and responded as quickly as possible.
- Participants fully understood the testing instructions.
- Participants would have informed the PI of any ailment that may have impaired their performance.
- Participants were not overly tired or under the influence of medication/drug.

- The psychological research software was able to accurately track transmission delays for foreperiod and stimulus onset, and reaction time.
- The integrated software maintained a one-to-one timing ratio during data acquisition.

Limitations

- Participants may have been engaged in sport that had a reaction time training component.
- Participants might have had reaction time practice from playing action video games or brain training games with a reaction time component.
- Participants may have been distracted by flu/cold symptoms (headache, watery eyes).
- The monitor was set to a refresh rate of 60hz.

CHAPTER 2: LITERATURE REVIEW

Currently, the stages of information processing, which can be defined with RT methods, remains the most popular model to explain how we perceive and plan to interact with our environment. However, the stages of information processing model is strictly a means of understanding central processing and lacks explanation of movement error or the need to adapt to a changing environment (feedback). This is important as we readily interact with our environment through movement; thus, further explanation is necessary about the peripheral processing that affects the quality of human movement. Further, there is no empirical evidence to support the stages of information processing model. As such, two largely impactful theories (closed-loop theory; schema theory and the generalized motor program) were developed to incorporate and better explain human interactions with the environment, which included feedback.

Closed-loop Theory

A closed-loop (self-regulating) system uses feedback (external or internal) to determine if an error exists in relation to a predetermined goal, which is the reference of correctness (see Figure 2). If the system detects a deviation from the reference of correctness, the system will adjust to compensate for the error. The thermostat is a typical example. The thermostat is set to a desired temperature (reference of correctness), the ambient temperature is frequently sampled (fed back to the system) and if there is a deviation from the reference (e.g., drop in temperature), the system will correct for this by turning on the furnace, which will stay on until the system error returns to zero.

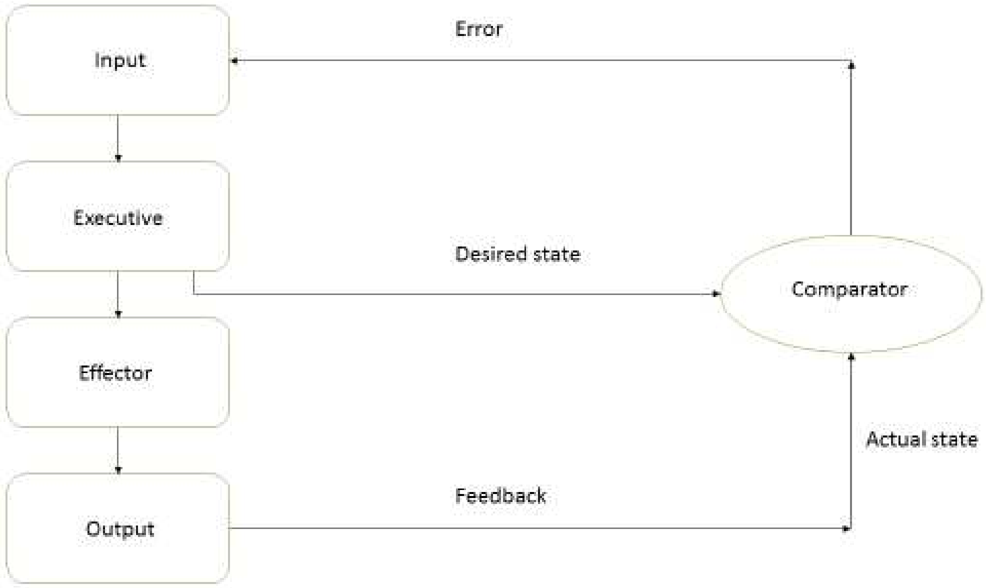

Figure 2. Closed-loop control model.

The closed-loop theory of motor learning (Adams, 1971) is a two-state theory employing cognitive and perceptual constructs, which operate in a closed-loop system, that separately initiate and fine-tune the movement, respectively. Perception is the first construct and is in the reference mechanism for error assessment in a motor learning task. The stimulus feedback (e.g., visual and proprioceptive) imprint a representation of themselves in memory on each trial. As the participant uses knowledge of results (KR) on each trial to improve performance, the response-produced feedback from each trial further strengthens the previous memory of what the correct response should be. This continual check of the reference of correctness with adjustments being made on the basis of the KR the performer has received, is called perceptual trace. It is the construct that fundamentally determines the extent of movement and the strength of the trace increases with practice and feedback on each acquisition trial. With sufficient practice to develop the perceptual trace, the performer will have the internal representation to use as information (provided response-produced feedback is sufficient) about their performance, even in the absence of KR. Therefore, KR and the correspondence between feedback and the perceptual trace, as sources of error information, combine to produce the trial-by-trial changes that constitute learning (Adams, 1987).

The second construct is cognitive and is called memory trace, which is non-perceptual and operates without feedback. The memory trace is a modest motor program that only chooses and initiates the motor response rather than controlling a longer sequence. Lastly, the memory trace that starts the movement is independent of both the feedback and the perceptual trace that regulates the movement after it has started (Adams, 1987).

The predominately perceptual theory requires feedback to be successful, with a primary tenet being the notion that acquiring and developing the capability to detect and correct errors was necessary for the learning process. Adams theory did very well with the instrumental learning of simple, self-paced, graded movements (e.g., drawing a line). However, all human movement does not reside under these circumstances.

Schema Theory

Though Adams closed-loop theory of motor learning garnered much support in the early 1970’s in the motor learning community for its applicability to physical education and performance enhancement, the success was short lived. A mere four years after Adams closed-loop theory was published, Schmidt (1975) detailed two lines of criticism against it. First, Adams theory relies too much on response-produced feedback and consequently fails to consider that movement sequences can be run off centrally without the aid of feedback. Second, that it fails to consider response variability, in which responding is flexibly adapted to a changing situation. To deal with these shortcomings, Schmidt (1975) developed the schema theory of discrete motor skill learning, though a significant portion was dedicated to motor programming as well as schema.

The schema concept is based on a set of rules that are developed by practice and experience across a lifetime, which described a relationship between the outcomes achieved on past attempts at running a program and the parameters chosen on those attempts. Similar to Adams (1971) memory trace and perceptual trace, Schmidt (1975) used the terms recall schema and recognition schema, respectively. Here, recall schema selects the values of the movement parameters that specify the particular movement to be made from those in the movement category. The recall schema depends on the integration of the new information from the actual outcome, the initial conditions, and the response specifications, to update the existing schema. On the other hand, recognition schema evaluates the correctness of the movement that is made and develops by integrating the initial conditions, the sensory consequences, and the actual outcome into the existing recognition schema (Schmidt, 1975). These two schemata get their capabilities by abstracting information from the parameters, knowledge of results, feedback, and initial conditions over the many times that the movements of a response category have been made (Adams, 1987).

Generalized Motor Program and Effector Independence

The concept of the motor program is that movements are structured and driven centrally, and that substantial portions of a movement can be run off without the regulatory assistance of response-produced feedback. Keele (1968) defined the motor program as a sequence of stored commands that is “structured before the movement begins and allows the entire sequence to be carried uninfluenced by peripheral feedback” (p. 387). Figure 3 demonstrates the open-loop model of the motor program, with the solid black arrows indicating the process will proceed unaffected by feedback. The open arrow indicates feedback of performance after the action has been completed (terminal feedback).

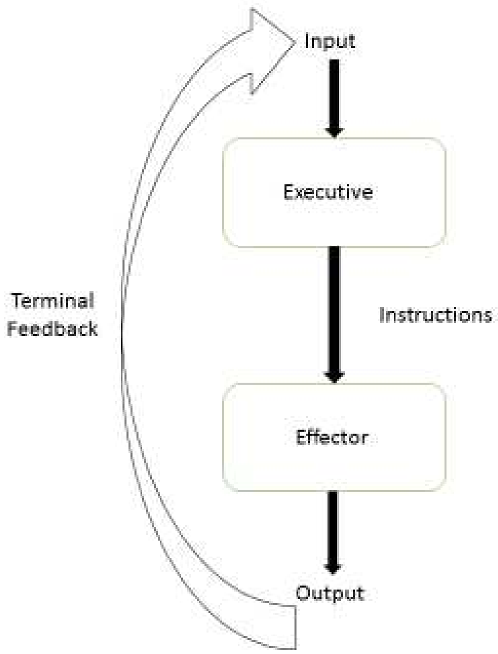

Figure 3. Open-loop control model.

However, there were two largely related theoretical setbacks to the motor program theory; the storage problem and the novelty problem. For example, serving a tennis ball will never be exactly as it was on the previous serve because there are too many degrees of freedom to consider, meaning each minute variation in muscular tension, posture, and segment-segment angle would require a separate program, which creates a storage problem in memory. MacNeilage (1970) was the first to describe this issue of storage using speech production, where he estimated approximately 100,000 programs would be required for speech itself, and clearly humans are capable of much more than speech. The novelty issue of motor programming brings to question how are we able to create new movements that are not inherently logical or meaningful for survival, as walking presumably is.

Schmidt (1975) added a unique feature to effectively solve the motor program problems of storage and novelty, which was that motor programs should be regarded as generalized. This generalization of the motor program (GMP) allows for any given program to be executed in countless ways to allow for the numerous variations we exhibit while performing a seemingly identical movement and for the creation of new movements. Central to the notion of the GMP are invariant features and variant features. Invariant features are the order of events, relative timing, and relative force, which make up the abstract structure of the motor program for a specific group of actions retained in memory. The action to be performed will have a characteristic pattern of activity that will manifest each time the program is implemented, regardless of the muscle(s) involved. This lack of effector definition in the abstract representation is known as effector independence (Verwey, 1999; Keele, Jennings, Jones, Caulton, & Cohen, 1995). The variant features of the GMP, known as parameters, are overall duration, overall force, and muscle-selection. These parameters need to be chosen before the program can unfold, as they decide the specifics of how to perform the movement. The movement parameters are allowed to vary with each act, and for that reason, the motor program can be thought of as generalized.

A clear example that incorporates both invariant features and parameters is handwriting. Though others have found more recent evidence (Bruce, 1994; Raibert, 1977; Merton, 1972), Lashley (1942) was the first to demonstrate both in one experiment. Lashley had his subjects write the words ‘motor equivalence’ with their dominant and non-dominant hands, both regularly and reversed in a mirror, and using their teeth. He was able to demonstrate that an individual would produce any letter in a very similar type of way each time it was written, representing a specific style, for example, an exaggerated tail on a lowercase “a”. This type of abstract pattern was seen regardless of the letter size, speed of writing, or muscle-selection parameters chosen. Clearly, there is a marked difference in the muscles used to write with the teeth versus the hand, however, each subject maintained their unique style of writing.

Given that the movement sequence did not vary from the same muscles of different limbs or with a very different and seemingly most unpracticed set of muscles (mouth), the motor program would reasonably be considered abstract and effector independent. The findings from these handwriting experiments lend support for the notion of invariant features forming a sequence of action in memory as opposed to a sequence of muscles, and have further been corroborated by extensive analyses (Castiello, Stelmach, & Lieberman, 1993; Wright, 1990).

Further evidence for this standpoint has come from several authors investigating bilateral-transfer (Shapiro, 1977; Keele, Cohen, & Ivry, 1990; Jordan, 1995; Keele, et al., 1995), demonstrating overall that a program developed with one side of the body could be replicated with the other, and that sequence learning during transfer could be retained. Similarly, Park and Shea (2002) dissociated the invariant features of relative time and force from the parameter errors related to the scaling of absolute time and force. They found that the relative timing errors observed during limb-to-limb transfer were no greater than when tested with the same limb used in acquisition or when comparing flexion (biceps) to extension (triceps). Additionally, Lai, Shea, Bruechert, & Little (2002) had participants perform key presses in a temporal pattern and found that regardless of manipulating the fingers used, reversing the role of each finger, or when moving a single finger from key to key, the relative-timing pattern remained virtually unchanged. Taken together, these studies provide strong evidence for the concept of effector independence within the motor program.

These theories by Adams (1971) and Schmidt (1975) made significant contributions to the motor learning field, expanding the stages of information processing model by incorporating the role of feedback. Though, both were not without fault. Where the closed-loop theory failed to adequately explain rapid, discrete actions, schema theory and the generalized motor program was able to rectify this void. However, both theories relied on central processes to explain human motor learning, with explanation at the peripheral level remaining absent.

Hierarchical Organization of the Brain

Near the end of the 19th century, John Hughlings Jackson introduced the concept of a hierarchically organized cerebral cortex with certain cortical areas responsible for integrating sensory and motor information at the highest level of the central nervous system. These higher-order regions of the brain, referred to as association areas, allow greater efficiency for mental processing by providing a way to associate sensory feedback to motor output. Functionally, visual information about form and color received by the retina is transmitted posteriorly by way of P cells to the parvocellular layers of the lateral geniculate nucleus in the thalamus (P pathway), which is then delivered to the primary visual cortex in the occipital lobe (Brodmann’s area 17). This information is then sent rostrally through the ventral pathway to the unimodal sensory association area of the occiptotemporal lobe (Brodmann’s area 37), where it is then projected to the anterior multimodal motor integration area in the prefrontal cortex of the frontal lobe (Brodmann’s area 8).

At this stage, what has been observed by the retina has been processed enough to begin developing a plan and a program for action, which will happen in the supplementary motor area and premotor area (collectively, Brodmann’s area 6). Once the program is ready, it is sent to the primary motor cortex for implementation (Brodmann’s area 4). The axons of the neurons from the primary motor cortex descend through the lateral corticospinal pathway where they merge onto the motor neurons in the ventral horn of the spinal cord, known as the final common pathway, and innervate the muscle(s) responsible for the physical action. From a motor behavior stand-point, Greene (1972) also perpetuated the notion of a hierarchical system of motor control. Greene theorized that a general goal is developed at the upper levels of the hierarchy. As the goal is passed on to the lower levels, the coordinative structure of action becomes increasingly tuned with internal and external environmental factors and ultimately results in the desired movement.

Fractionated Reaction Time

Reaction time has been the focus of a large number of research studies over the last 100 years, covering a broad range of topics such as physical and cognitive exercise (León, Ureña, Bolaños, Bilbao, & Oña, 2015), alcohol and caffeine (Oborne, 1983; Martin & Garfield, 2006), Parkinson's disease (Kwon, Park, Kim, Eom, Hong, Koh, & Park, 2014), and military occupational hazards (Mortazavi, Taeb, & Dehghan, 2013). However, it wasn't until the mid-1960's that reaction time, as a whole, would be divided into two distinct parts (Weiss, 1965; Botwinick & Thompson, 1966a). Weiss (1965) published a seminal paper demonstrating that total reaction time can be fractionated (FRT) into central and peripheral processes by measuring the onset of electrical activity in the agonist muscle. Timing of central processing, as indexed by premotor time (PMT), is the time from stimulus onset to the appearance of the muscle action potential. Timing of peripheral processing, as indexed by motor time (MT), is the duration from muscle firing to the overt behavior. Figure 4 shows the pertinent events in FRT with the EMG record of the abductor pollicis brevis for one trial.

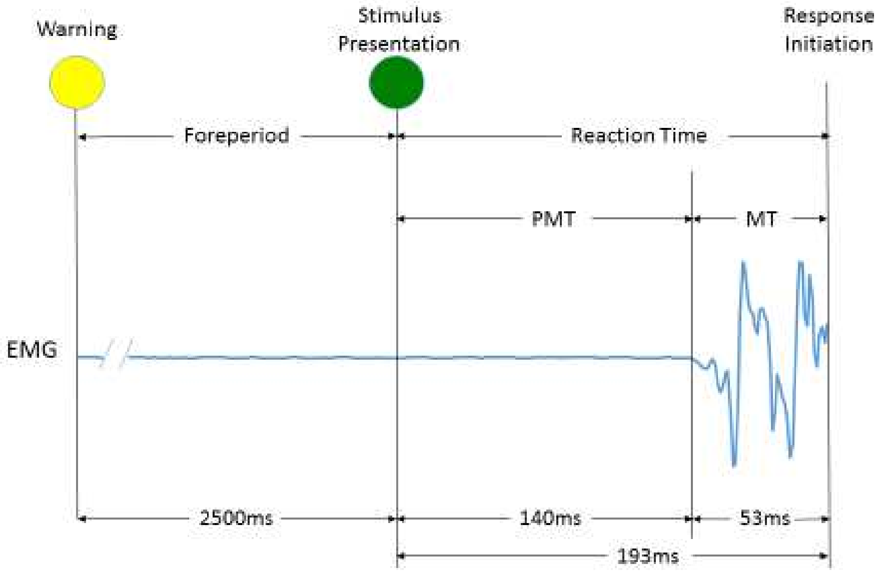

Figure 4. Fractionated reaction time events.

This method has shown to be useful in obtaining information about where the effect of various independent variables reside, such as in large-scale movements (Anson, 1982, 1989; Christina, Fischman, Vercruyssen, & Anson, 1982; Christina & Rose, 1985; Fischman, 1984), with accuracy demands (Sidaway, 1991; Fischman & Mucci, 1990) and inertial load (Anson, 1989). Surprisingly, since Weiss's paper, relatively few researchers have adopted use of the FRT technique. For example, the time between a warning signal and the presentation of the stimulus is called the foreperiod, which several researchers have manipulated to investigate its effects on total RT (Niemi & Näätänen, 1981; Klemmer, 1956, 1957a; Nickerson & Burnham, 1969; Karlin, 1959; Drazin, 1961; Näätänen, 1972). Though few have investigated foreperiod regularity in FRT studies (Weiss, 1965; Botwinick & Thompson, 1966a; Kawama, 1996).

Electromechanical Delay and Motor Time

From a biomechanical perspective, electromechanical delay (EMD) is defined by the electromechanical and biochemical occurrences, in concert with the muscles' morphological properties, which are responsible for the delay in muscular tension development. With reference to Newton's second law of motion, a muscle with greater mass (or reasonably, a greater resistance arm) will require a greater net force to initiate movement of the respective body segment. Though, in the realm of motor behavior, the neuromotor events that collectively determine the EMD, here termed motor time (MT), may theoretically, depending on the situation, also be affected by central processing complexities. Cavanagh & Komi (1979) defined EMD as the difference between the onset of the EMG signal and the development of muscular tension, which is comprised of several components. These are: (1) conduction of the motor unit action potential along the T-tubule system; (2) release of calcium by the sarcoplasmic reticulum; (3) cross-bridge formation between actin and myosin filaments, and the subsequent tension development in the contractile component (CC); (4) stretching of the series elastic component (SEC). Several studies have measured EMD in the upper extremity, reporting latencies ranging from approximately 25 milliseconds to 85 milliseconds (Howatson, Glaister, Brouner, & van Someren, 2009; Vint, McLean, & Harron, 2001; Gabriel & Boucher, 1998; Cavanagh & Komi, 1979; Norman & Komi, 1979), though only males participated in each of these studies.

CHAPTER 3: EXPERIMENT ONE

In Experiment 1, regular and irregular foreperiods were manipulated by block to specifically impact central processing time only. Here, the physical response remained constant (thumb press), while fluctuating the time course of when the stimulus appeared after a warning signal (foreperiod). It is thought that an irregular foreperiod will not allow the participant to accurately anticipate (central processing trait) the stimulus onset, and therefore, will increase the premotor time necessary to respond. Further, a regularly occurring foreperiod may allow pre-programming of the response (response selection and programming), which is constructed centrally, and therefore should decrease the premotor time in the regular foreperiod blocks. Based on previous findings (Weiss, 1965; Botwinick & Thompson, 1966a; Niemi & Näätänen, 1981), it was predicted that significantly shorter reaction times and premotor times would be observed during the regular foreperiod blocks compared to the irregular foreperiod blocks, with no appreciable difference in motor time between foreperiod conditions or across blocks. It was also predicted that reaction time would significantly decrease with practice across blocks.

Of further interest, was to determine if grouping all regular versus irregular foreperiod blocks would demonstrate a significant difference regarding the block order of condition (sequence) presented to the participant. Where: regular-group was made up of all regular foreperiod blocks from all participants; irregular-group was made up of all irregular foreperiod blocks from all participants; sequence1 was made up of blocks 1, 3, and 5 from all participants; sequence2 was made up of blocks 2, 4, and 6 from all participants. Additionally, sex was compared against both regular and irregular-groups.

Methods

Participants

Twenty-two healthy male (n = 10) and female (n = 12) undergraduate and graduate students, aged 19-30 who were enrolled in Kinesiology, Health and Sport Studies courses at Wayne State University were recruited for participation in the study. For inclusion in the study, participants must have been free from any neurological conditions, stroke, blindness, and injury to their right-side upper extremity. In compliance with the Human Investigation Committee guidelines, approval from the Institutional Review Board was obtained and all participants signed the Research Informed Consent Form (see Appendix) prior to the investigation. None of the participants had any previous knowledge of the hypothesis being tested or experience with the experimental task.

Apparatus

The apparatus was an interfaced unit consisting of several pieces of hardware and software. This newly created method allows for simultaneous integration of data representing central and peripheral processes, which introduces a more refined technique of data acquisition to the scientific community. A desktop computer (Dell, Windows XP) was used to integrate E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) with a MP100 data acquisition and analysis system with Acq*Knowledge* software (BIOPAC Systems, Inc., Goleta, CA) to simultaneously record reaction time using a Serial Response Box (SRB 200A, Psychology Software Tools). The surface electromyographic signal (sEMG) was collected from the abductor pollicis brevis (APB) using small, pre-gelled, cloth based electrodes (EL504, BIOPAC Systems). All participants had their elbow and shoulder measured with a Zimmer goniometer (No. 137; Warsaw, IN) to ensure arm position consistency was maintained throughout the experiment. The SRB was placed on a short response table on the right side of the participant. All responses were made with the SRB.

Task

The task required the participants to be seated at a standard table, positioned so that they may comfortably depress the response key on the SRB placed on a short table to their right, while facing the monitor situated 18” in front of them. The task was to depress the response key as rapidly as possible upon onset of the visual stimulus (green orb), which was accomplished by thumb opposition. The participants initiated testing by reading the instructions presented on the monitor in front of them and depressing the response key with their thumb when ready. The testing area layout is pictured in Figure 5 and a detailed view of the serial response box is shown in Figure 6.

Figure 5. Testing area layout for Experiment 1.

Figure 6. Detailed picture of the serial response box.

Procedure

All participants were seated in a solid metal chair at a standard table in a well-lit room. After explaining the task and providing a demonstration, the participants were prepped for sEMG recording. The muscular activity of each responding muscle was monitored with concurrent biofeedback prior to testing. This was necessary to ensure the participant could maintain an inactive muscle until the presentation of the stimulus. The monitor displayed the instructions for the task and the participant was prompted to depress the response key on the SRB with their thumb to initiate the testing session, which was repeated each block. The participants were presented with a series of three different colored orbs (in order: red-yellow-green) shown one-at-a-time (see

Figure 7). The red orb represented a warning that the trial has commenced. The yellow orb represented the beginning of a regular or irregular foreperiod, which lead to the stimulus. The green orb represented the visual stimulus that they were instructed to respond to.

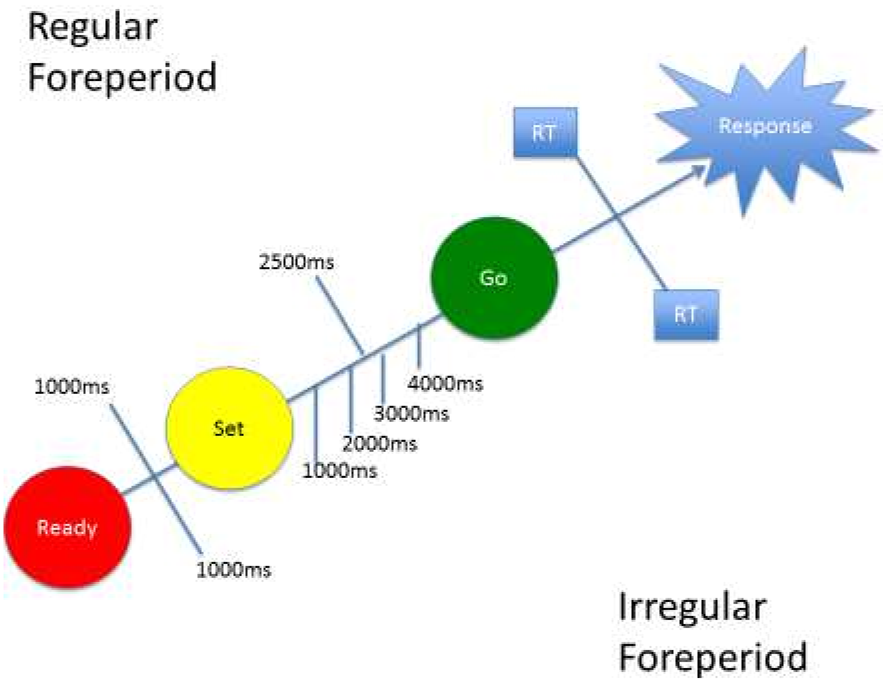

Figure 7. Representation of foreperiod condition with sequence of trial events.

The participants were asked to respond as quickly as possible to the visual stimulus by depressing the response key with their thumb. All participants used their right thumb to complete all trials. The participants were randomly divided into one of two foreperiod conditions (regular or irregular). All participants completed six blocks of eight trials, alternating the foreperiod condition for each block (e.g., the first participant had a regularly occurring foreperiod for all trials in blocks 1, 3, and 5. While during blocks 2, 4, and 6, the participant was presented with one-of-four unique foreperiods that were equally and randomly generated). The order of foreperiod condition was counterbalanced from participant to participant (e.g., participant 1 had blocks 1, 3, and 5 present a regular foreperiod, and blocks 2, 4, and 6 presented an irregular foreperiod.

Participant 2 had blocks 1, 3, and 5 present an irregular foreperiod, and blocks 2, 4, and 6 presented a regular foreperiod). One second separated trials and sixty seconds separated blocks.

Abductor Pollicis Brevis Positioning

The response table height was adjusted so that the SRB could be positioned to allow their thumb to comfortably rest on the response key, without force, and with the weight of their hand resting motionless to the side of the SRB.

Regular Foreperiod Trials

The participants saw a red orb appear on the monitor for 1000 ms, then immediately changed color to yellow and remained yellow for 2500 ms. The orb then immediately turned green and remained on the monitor until the participant depressed the response key. Immediately following each trial, the monitor displayed the participants' reaction time for 2000 ms. 1000 ms of white screen separated trials.

Irregular Foreperiod Trials

The participants saw a red orb appear on the monitor for 1000 ms, then immediately changed color to yellow and remained yellow for one-of-four possible durations (1000 ms, 2000 ms, 3000 ms, or 4000 ms), which occurred equally and in random order. After one-of-the-four randomly generated durations of the yellow orb expired, the orb immediately turned green and remained on the monitor until the participant depressed the response key. Immediately following each trial, the monitor displayed the participants' reaction time for 2000 ms. 1000 ms of white screen separated trials.

sEMG Recording

Simultaneously with the reaction time trials, all participants had their sEMG recorded from their APB and synced with their reaction time in order to fractionate it into its premotor (central) and motor (peripheral) components. The area over the muscle was lightly abraded with a dry, coarse sponge, which effectively removed dead skin cells and allowed the skin site to establish a high conductivity with the electrode (Hardware guide: EL500 Series [PDF document] retrieved from biopac.com). The cloth disposable square-shaped (2.5 cm x 2.5 cm) pre-gelled bipolar Ag/AgCl snap surface electrodes (EL504, BIOPAC Systems) were placed over the belly of the muscle (see Figure 8), parallel with the muscle fiber direction, at an inter-electrode distance (center to center) of 10 mm.

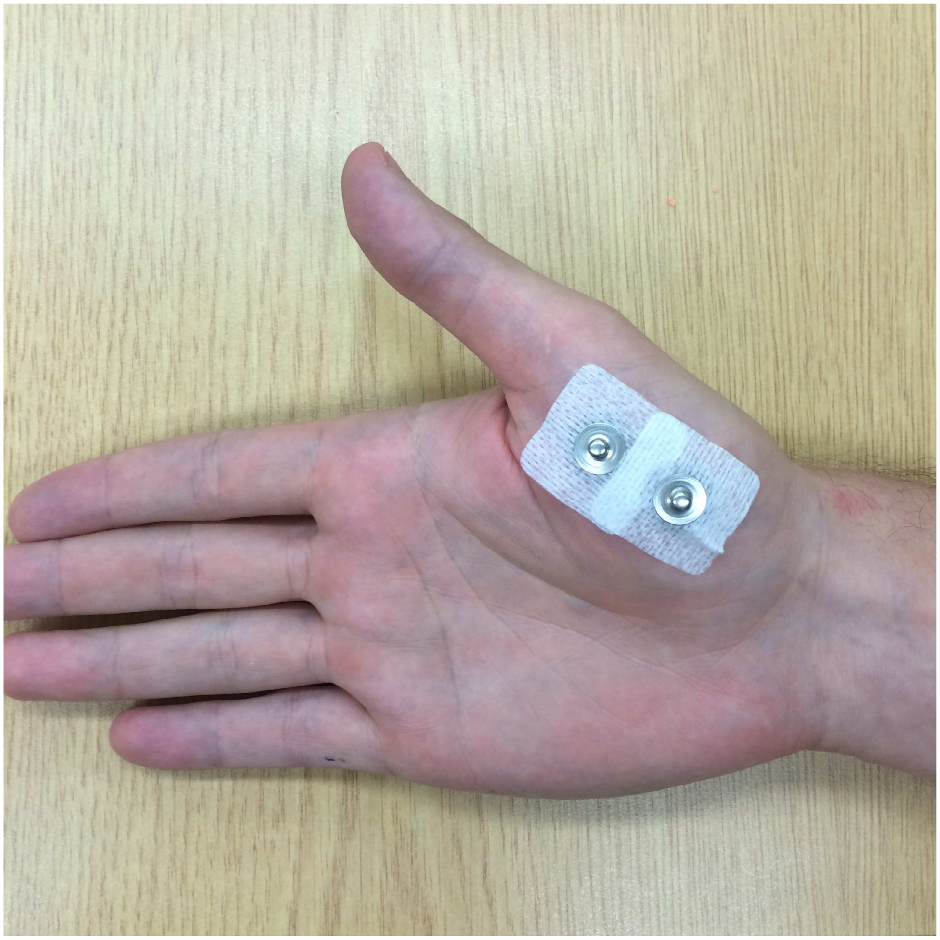

Figure 8. Electrode placement over belly of abductor pollicis brevis.

Data Collection

All data was collected digitally (on software) through the interfaced components. The BIOPAC MP100 data acquisition and analysis system used the Acq*Knowledge* software to digitally record the sEMG signal, which was integrated and time synced with the E-Prime 2.0 software in order to combine the temporal measures of fractionated reaction time with the physiological measure of sEMG.

Measurement

The dependent measure of time was averaged per block to produce a mean reaction time (mRT), mean premotor time (mPMT), and mean motor time (mMT) to evaluate performance across blocks. mRT was the average time taken to initiate a physical response once the visual stimulus appeared, which represents the culmination of the mPMT and mMT. mPMT was the average time taken from stimulus onset to the firing of the muscle action potential, which represents central processing time. mMT was the average time from the appearance of the muscle action potential to the initiation of the physical response, which represents peripheral processing time. In equation form:

$$RT = PMT + MT$$

Where MT is subtracted from RT to obtain PMT.

RTs greater than 600 ms were assumed to indicate a lack of task vigilance, and MTs less than 20 ms or greater than 100 ms were assumed to indicate equipment error, and were omitted during data analysis.

This experiment used within-participant's and between-participant's designs, and the data from the subjects was characterized using descriptive data analysis. Three ANOVAs were generated to determine differences within and between groups. The Dependent Variables measured were RT, PMT, and MT. Means, standard deviations, and standard error of the mean for each dependent measure were calculated. The Independent Variable was foreperiod duration. The order of foreperiod regularity was counter-balanced across participants. A probability value of $p <$ 0.05 was accepted as significant for differences. All statistical analyses were performed using SAS Version 9.2 (SAS Institutes, Inc., Cary, NC).

Results

For each condition, mean reaction time (mRT), mean premotor time (mPMT), and mean motor time (mMT) were calculated for each participant and evaluated employing three separate analyses of variance (ANOVAs). Firstly, was a 2 (foreperiod condition [regular or irregular]) x 6 (blocks) ANOVA, with repeated measures on conditions and blocks. Secondly, was a 2 (foreperiod group [regular or irregular]) x 2 (sequence [1 or 2]) ANOVA, between participant's design. Thirdly, was a 2 (sex [female or male]) x 2 (foreperiod group [regular or irregular]) ANOVA, between participant's design.

Foreperiod Condition and Blocks

Mean Reaction Time (mRT)

The analysis indicated that the main effect of foreperiod condition (regular, $M = 231.74$; irregular, $M = 253.99$), $F(1, 20) = 72.15$, ($p<.0001$) with an R^2 of 1.0, was significant. Duncan's multiple range test on foreperiod condition indicated that mRT was significantly shorter for the regular foreperiod condition (see Figure 9). The main effect of block $F(5, 80) = 3.17$, ($p=.0116$) was also significant. Duncan's multiple range test on blocks indicated that mRT was longer in block 1 than in all other blocks, and that there was no significant difference between blocks 2-6. No interaction existed.

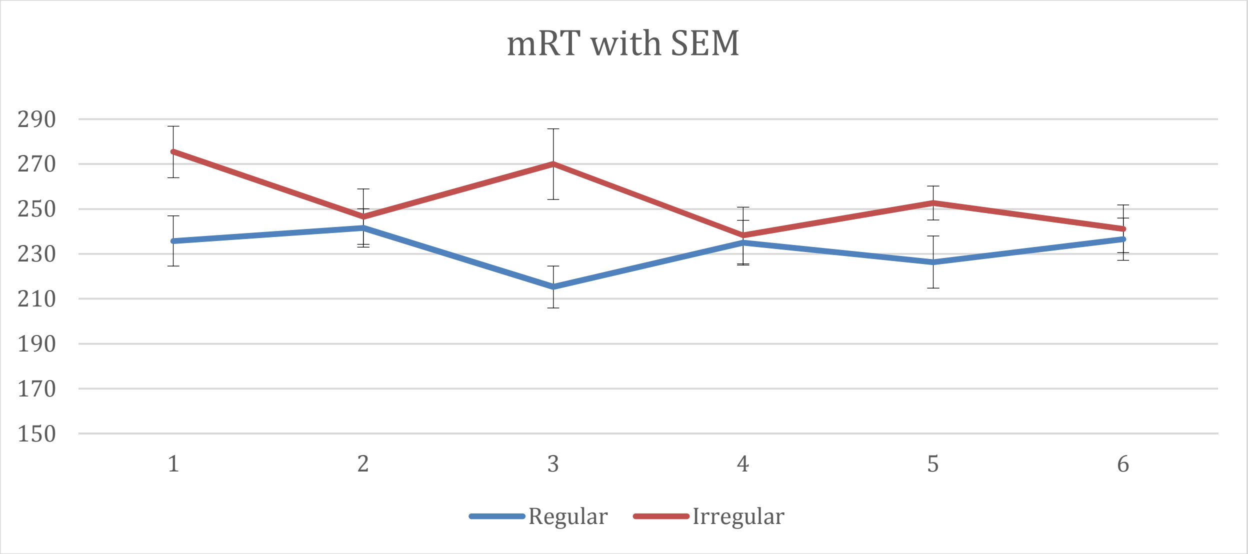

Figure 9. Mean reaction time with standard error of the mean across blocks maintaining counter-balanced design.

Mean Premotor Time (mPMT)

The analysis indicated that the main effect of foreperiod condition, (regular, $M = 175.71$; irregular, $M = 200.46$), $F(1, 20) = 82.16$, ($p<.0001$) with an R^2 of 1.0, was significant. Duncan's multiple range test on foreperiod condition indicated that mPMT was significantly shorter for the regular foreperiod condition (see Figure 10). The main effect of block $F(5, 80) = 2.67$, ($p=.0277$) was also significant. Duncan's multiple range test on blocks indicated that mPMT was not significantly different between blocks 1 and 2, however, mPMT in block 1 was significantly longer than in blocks 3-6, with no significant difference between blocks 2-6. No interaction existed.

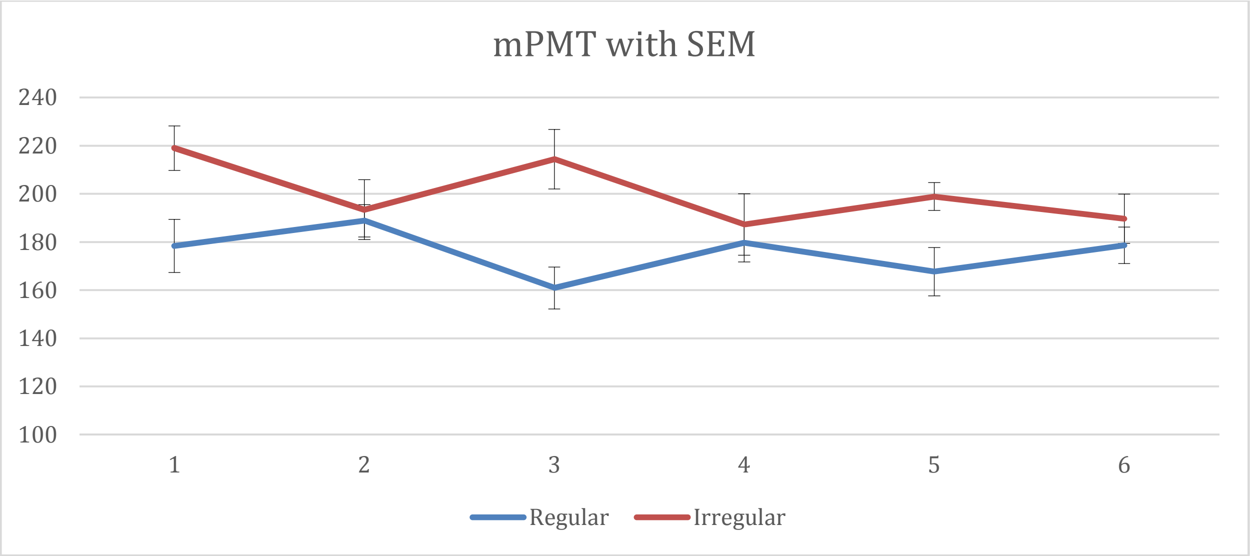

Figure 10. Mean premotor time with standard error of the mean across blocks maintaining counter-balanced design.

Mean Motor Time (mMT)

There were no significant main effects for condition or block (see Figure 11), and no interaction existed.

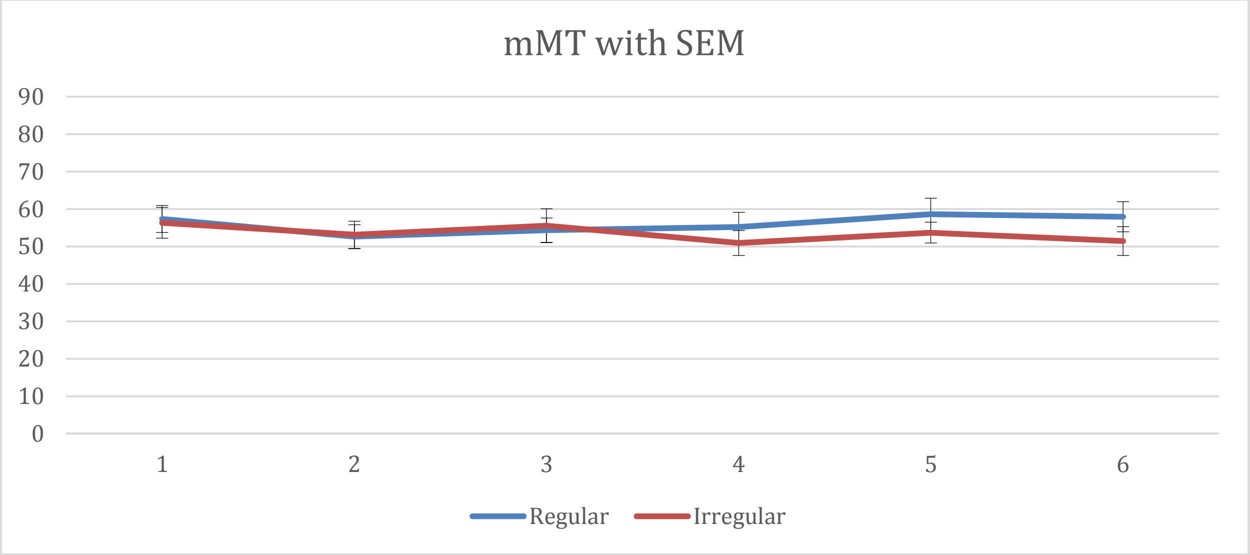

Figure 11. Mean motor time with standard error of the mean across blocks maintaining counter-balanced design.

Figure 12 demonstrates the real-time difference between a typical regular and irregular foreperiod trial. Reaction time, premotor time, and motor time for the regular foreperiod (2,500ms) trial was 205ms, 161ms, and 44ms, respectively. Reaction time, premotor time, and motor time for the irregular foreperiod (1,000ms) trial was 267ms, 218ms, and 49ms, respectively.

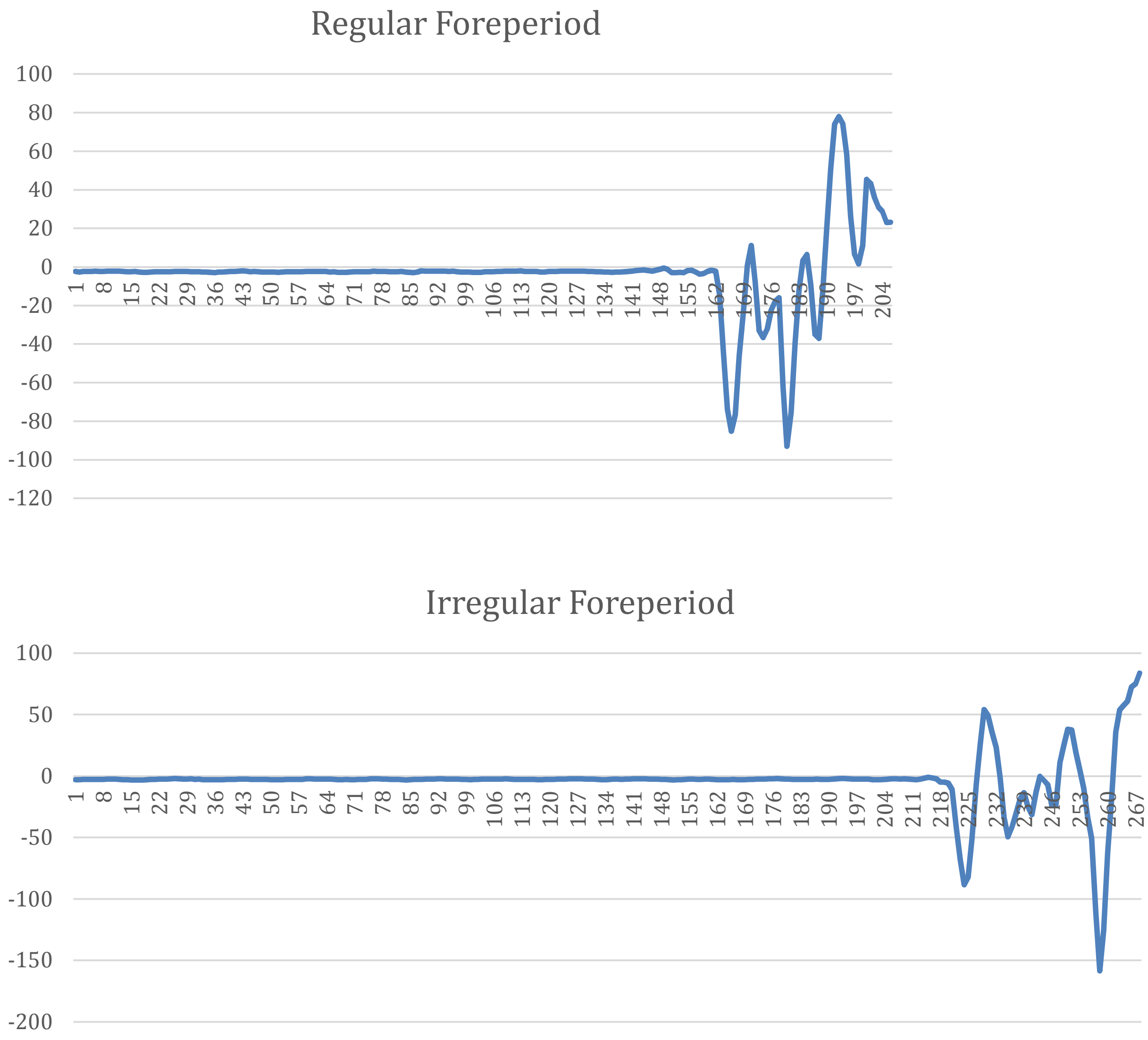

Figure 12. Time-matched comparison of typical performance between foreperiod conditions.

Foreperiod-Group and Sequence

In order to evaluate performance among all blocks of regular foreperiods versus irregular foreperiods for all participants, two foreperiod-groups were formed. All regular foreperiod blocks comprised Reg-Group, while all irregular foreperiod blocks comprised Irreg-Group. In order to determine if the order in which the foreperiod condition was presented had an effect on performance, two sequences were formed. Sequence1 represented all blocks numbered 1, 3, and 5, while sequence2 represented all blocks numbered 2, 4, and 6. The mean performance scores and associated standard error of the mean are presented in Table 1.

Mean Reaction Time (mRT)

The analysis indicated that the main effect of foreperiod-group, (regular, *M* = 231.74; irregular, *M* = 253.99), *F*(1, 128) = 12.49, (*p*=.0006) with an R^2 of .14, was significant. Duncan's multiple range test on foreperiod-group indicated that mRT was significantly shorter for the Reg-Group. There was also a significant interaction between foreperiod-group and sequence, *F*(1, 128) = 8.14, (*p*=.005). For Reg-Group, sequence1 led to the shortest mRT. For Irreg-Group, sequence1 led to the longest mRT (see Figure 13).

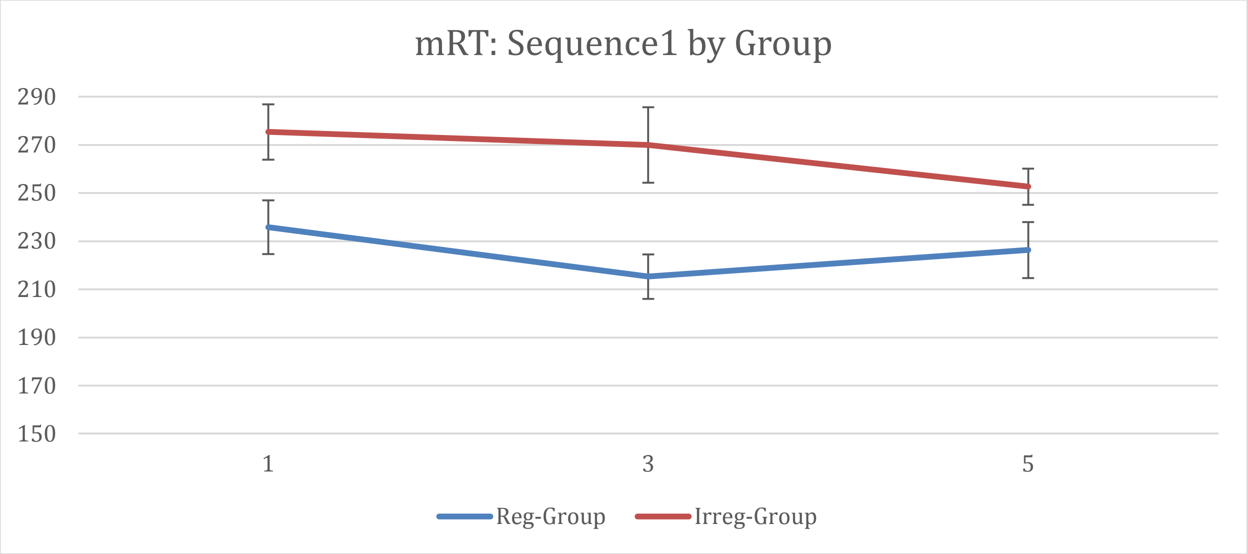

Figure 13. Mean reaction time with standard error of the mean separating blocks by sequence order and foreperiod group.

Mean Premotor Time (mPMT)

The analysis indicated that the main effect of foreperiod-group, (regular, M = 175.71; irregular, M = 200.46), $F(1, 128) = 19.53$, ($p<.0001$) with an R^2 of .19, was significant. Duncan's multiple range test on foreperiod-group indicated that mPMT was significantly shorter for Reg-Group. There was also a significant interaction between foreperiod-group and sequence, $F(1, 128) = 9.24$, ($p=.0029$). For Reg-Group, sequence1 led to the shortest mPMT. For Irreg-Group, sequence1 led to the longest mPMT (see Figure 14).

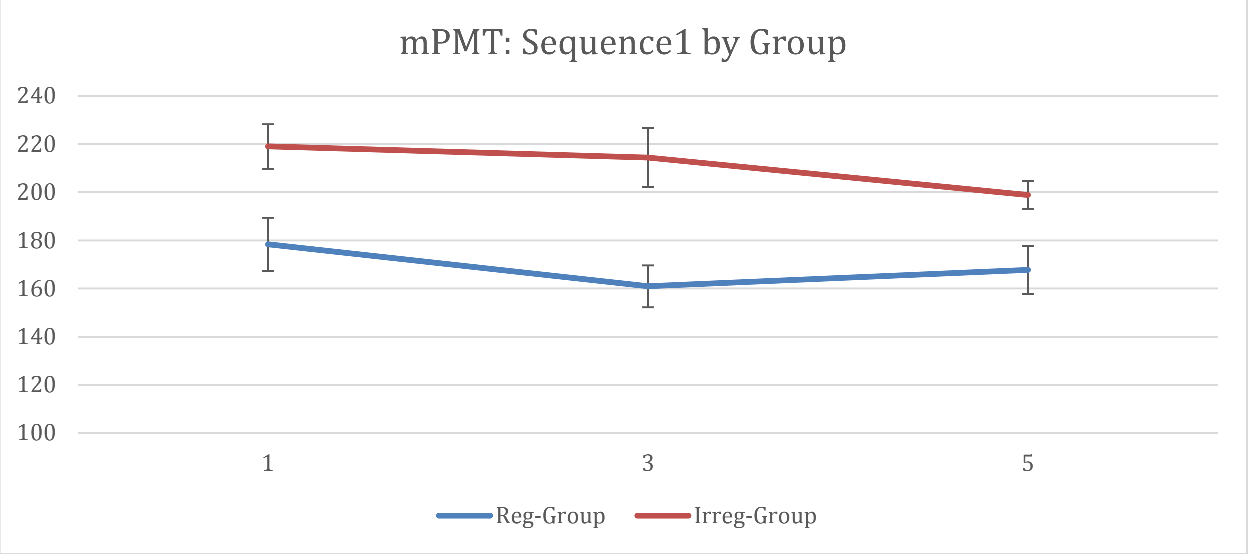

Figure 14. Mean premotor time with standard error of the mean separating blocks by sequence order and foreperiod group.

Mean Motor Time (mMT)

There were no significant main effects for foreperiod-group or sequence, and no interaction existed.

Table 1: The Mean Performance Scores and ± SEM of RT, PMT, and MT for the Foreperiod Group X Sequence Order Interaction.

	Group (RT)		Group (PMT)		Group (MT)	
	1	2	1	2	1	2
S1	225.78* ± 6.18	265.99* ± 6.96	169.00* ± 5.71	210.78* ± 5.51	56.78 ± 2.12	55.21 ± 2.17
S2	237.70 ± 5.23	241.99 ± 6.67	182.42 ± 4.27	190.14 ± 6.65	55.29 ± 2.12	51.85 ± 2.03

* $P < 0.05$

Foreperiod Group and Sex

Mean Reaction Time (mRT)

The analysis indicated that the main effect of sex, (female, $M = 237.31$; male, $M = 249.54$), $F(1, 128) = 3.60$, ($p=.0601$) with an R^2 of .11, was not significant, however, there was a trend for females to respond faster. The main effect of foreperiod-group, (regular, $M = 231.74$; irregular, $M = 253.99$), $F(1, 128) = 12.00$, ($p=.0007$) was significant. Duncan's multiple range test on foreperiod-group indicated that mRT was significantly shorter for Reg-Group. No interaction existed.

Mean Premotor Time (mPMT)

The analysis indicated that the main effect of sex, (female, $M = 181.90$; male, $M = 195.51$), $F(1, 128) = 5.69$, ($p=.0185$) with an R^2 of .16, was significant. Duncan's multiple range test on sex indicated that mPMT was significantly shorter for females. The main effect of foreperiod-group, (regular, $M = 175.71$; irregular, $M = 200.46$), $F(1, 128) = 18.97$, ($p<.0001$) was also significant. Duncan's multiple range test on foreperiod-group indicated that mPMT was significantly shorter for Reg-Group. No interaction existed.

Mean Motor Time (mMT)

There were no significant main effects for sex or foreperiod-group, and no interaction existed. The mean performance scores and associated standard error of the mean are presented in Table 2.

Table 2: The Mean Performance Scores and ± SEM of RT, PMT, and MT for the Sex X Foreperiod Group ANOVA.

	Group (RT)		Group (PMT)		Group (MT)	
	Reg	IRreg	Reg	IRreg	Reg	IRreg
Female	227.01 ± 5.27	247.60 ± 5.19	169.46* ± 4.81	194.33* ± 4.63	57.55 ± 2.19	53.27 ± 1.94

Male	237.42 ± 6.32	261.65 ± 9.00	183.20 ± 5.31	207.81 ± 8.01	54.22 ± 1.95	53.84 ± 2.33

* $P < 0.05$

Summary

In agreeance with the hypotheses, the within-participant's analysis of foreperiod condition and block indicated that mRT and mPMT were significantly shorter in the regular foreperiod condition. However, lacking full agreeance, was that mRT did not progressively decrease across blocks. mRT was longer in block 1 than in all other blocks, with no significant difference between blocks 2 through 6. mPMT was not significantly different between blocks 1 and 2, however, block 1 was significantly longer than blocks 3 through 6, with no significant difference between blocks 2 through 6. The observed plateau in RT across the majority of blocks may have been due to the counter-balanced design. Further, there was no significant interaction between foreperiod condition and block.

Two foreperiod-groups were created in order to compare all regular versus irregular-foreperiod blocks, named Reg-Group and Irreg-Group, respectively. Additionally, two sets of sequences were created in order to compare the effect of condition ordering in the counter-balanced design. Sequence1 represented all blocks numbered 1, 3, and 5, while sequence2 represented all blocks numbered 2, 4, and 6. The between-participant's analysis of foreperiod-group and sequence indicated that mRT and mPMT were significantly shorter in the Reg-Group. Particularly interesting was the finding of a significant interaction between foreperiod-group and sequence for mRT and mPMT. For the Reg-Group, sequence 1, 3, 5 led to the shortest mRT. In other words, the participants who began the experiment with the regular foreperiod condition, produced the shortest mRT and mPMT. In contrast, the Irreg-Group with sequence 1, 3, 5, led to the longest mRT and mPMT. In other words, the participants who began the experiment with the irregular foreperiod condition, produced the longest mRT and mPMT. This interaction demonstrates the effect of sequence can change, depending on the foreperiod-group. Functionally, beginning with an irregular foreperiod block, opposed to a regular foreperiod block, interferes with the ability to develop an adaptable strategy to contend with alternating blocks of irregular and regular foreperiods.

The between-participant's analysis of sex and foreperiod-group indicated that mRT did not reach significance for sex, though there was a trend for females to have a shorter mRT. However, females demonstrated a significantly shorter mPMT. This interesting finding indicates that females are more efficient at information processing than males when the task requires alternating the foreperiod condition by block.

There were no significant main effects for condition, block, foreperiod-group, sequence, sex, or interactions for all analyses of mMT.

CHAPTER 4: EXPERIMENT TWO

In Experiment 2, muscle size was manipulated by block to specifically impact peripheral processing time only. Here, the foreperiod remained constant (2500 ms), while alternating muscle size by block (abductor pollicis brevis, APB and lateral triceps brachii, LTB). A smaller muscle is likely to be responsible for movement of a smaller anatomical unit (thumb opposition vs. forearm extension), and therefore require a lower level of neuromotor excitation to elicit a physical response, which would be manifest in a shorter RT. Based on previous findings (Henneman, Somjen, and Carpenter, 1965; Anson, 1982; Klapp, 1981), it was predicted that significantly shorter reaction times and motor times would be observed during the APB blocks compared to the LTB blocks, with no appreciable difference in premotor time between muscle size conditions or across blocks. It was also predicted that reaction time would significantly decrease with practice across blocks. Further, based on the results from several effector-independence studies (Lai, Shea, Bruechert, & Little, 2002; Wright, 1990; Schmidt, 1975), it was predicted that the relative-timing of PMT and MT to RT between the two different size muscles would remain stable.

Of further interest, was to determine if grouping all APB versus LTB blocks would demonstrate a significant difference regarding the block order of condition (sequence) presented to the participant. Where: Small-Group was made up of all APB blocks from all participants; Large-Group was made up of all LTB blocks from all participants; sequence1 was made up of blocks 1, 3, and 5 from all participants; sequence2 was made up of blocks 2, 4, and 6 from all participants. Additionally, sex was compared against both groups of muscle size condition.

Methods

Participants

Twenty-two healthy male (n = 11) and female (n = 11) undergraduate and graduate students, aged 19-30 who were enrolled in Kinesiology, Health and Sport Studies courses at Wayne State University were recruited for participation in the study (N = 22). For inclusion in the study, participants must have been free from any neurological conditions, stroke, blindness, and injury to their right-side upper extremity. In compliance with the Human Investigation Committee guidelines, approval from the Institutional Review Board was obtained and all participants signed the Research Informed Consent Form (see Appendix) prior to the investigation. None of the participants had any previous knowledge of the hypothesis being tested or experience with the experimental task.

Apparatus

The apparatus was an interfaced unit consisting of several pieces of hardware and software. A desktop computer (Dell, Windows XP) was used to integrate E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) with a MP100 data acquisition and analysis system with Acq*Knowledge* software (BIOPAC Systems, Inc., Goleta, CA) to simultaneously record reaction time using a Treadlite II T-91-S footswitch (Linemaster Switch Corporation, Woodstock, CT) connected to a Serial Response Box (SRB 200A, Psychology Software Tools). The surface electromyographic signal (sEMG) was collected from the abductor pollicis brevis (APB) and lateral triceps brachii (LTB) using small, pre-gelled, cloth based electrodes (EL504, BIOPAC Systems). All participants had their elbow and shoulder measured with a Zimmer goniometer (No. 137; Warsaw, IN) to ensure arm position consistency was maintained throughout the experiment. The SRB and footswitch were placed on a short response table on the right side of the participant. All APB and LTB responses were made with the SRB and footswitch, respectively.

Task

The task required the participants to be seated at a standard table, positioned so that they may comfortably depress the response key on the SRB (see Figure 6) or footswitch (see Figure 16), both placed on a short table to their right, while facing the monitor situated 18” in front of them. The task was to respond as rapidly as possible upon onset of the visual stimulus (green orb), which was accomplished by either thumb opposition or elbow extension, of the APB or LTB, respectively. The participants initiated testing by reading the instructions presented on the monitor in front of them and pressing the response key or footswitch with their right hand when ready. The testing area layout is pictured in Figure 15 and a detailed view of the footswitch is shown in Figure 16.

Figure 15. Testing area layout for Experiment 2.

Figure 16. Detailed picture of the footswitch.

Procedure

All participants were seated in a solid metal chair at a standard table in a well-lit room. After explaining the task and providing a demonstration, the participants were prepped for sEMG recording. The muscular activity of each responding muscle was monitored with concurrent biofeedback prior to testing. This was necessary to ensure the participant could maintain an inactive muscle until the presentation of the stimulus. The monitor displayed the instructions for the task and the participant was prompted to depress the response key or footswitch to initiate the testing session, which was repeated each block. The participants were presented with a series of three different colored orbs (in order: red-yellow-green) shown one-at-a-time (see Figure 17). The red orb represented a warning that the trial has commenced. The yellow orb represented the beginning of a regular foreperiod, which lead to the stimulus. The green orb represented the visual stimulus that they were instructed to respond to.

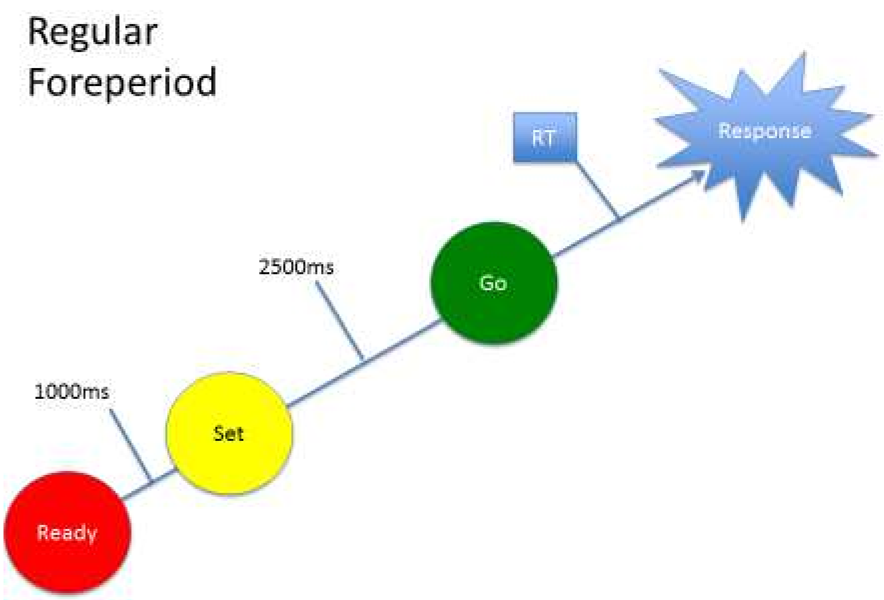

Figure 17. Experiment 2 trial procedure with regular foreperiod.

The participants were asked to respond as quickly as possible to the visual stimulus by depressing the response key with their thumb or footswitch with their palm. All participants used their right hand to complete all trials. The participants were randomly divided into one of two muscle size conditions (small [APB] or large [LTB]). All participants completed six blocks of eight trials with a regular foreperiod, alternating muscle size for each block (e.g. Participant 1 responded with thumb opposition for all trials in blocks 1, 3, and 5. While responding with elbow extension for blocks 2, 4, and 6). The order of the muscle size condition was counter-balanced from participant to participant (e.g. Participant 1 responded with thumb opposition during blocks 1, 3, and 5, and responded with elbow extension during blocks 2, 4, and 6. Participant 2 responded with elbow extension during blocks 1, 3, and 5, and responded with thumb opposition during blocks 2, 4, and 6). One second separated trials and sixty seconds separated blocks.

Abductor Pollicis Brevis Positioning

The response table height was adjusted so that the SRB could be positioned to allow their thumb to comfortably rest on the response key, without force, and with the weight of their hand resting motionless to the side of the SRB.

Lateral Triceps Brachii Positioning

The response table height was adjusted so that the footswitch could be positioned to allow their palm to comfortably rest on the footswitch, without force, and with the elbow near full extension (5-10 degrees of flexion). The participant was instructed to remain seated upright at all times with their shoulder at zero degrees of flexion to ensure the action was driven from the triceps.

Regular Foreperiod Trials

The participants saw a red orb appear on the monitor for 1000 ms, then immediately changed color to yellow and remained yellow for 2500 ms. The orb then immediately turned green and remained on the monitor until the participant depressed the response key or footswitch. Immediately following each trial, the monitor displayed the participants' reaction time for 2000 ms. 1000 ms of white screen separated trials.

sEMG Recording

Simultaneously with the reaction time trials, all participants had their sEMG recorded from their APB and LTB and synced with their reaction time in order to fractionate it into its premotor (central) and motor (peripheral) components. The area over the muscle was lightly abraded with a dry, coarse sponge, which effectively removed dead skin cells and allowed the skin site to establish a high conductivity with the electrode (Hardware guide: EL500 Series [PDF document] retrieved from biopac.com). The cloth disposable square-shaped (2.5 cm x 2.5 cm) pre-gelled bipolar Ag/AgCl snap surface electrodes (EL504, BIOPAC Systems) were placed over the belly of the muscle, parallel with the muscle fiber direction, at an inter-electrode distance (center to center) of 10 mm for the APB (see Figure 8) and 20 mm for the LTB (see Figure 18).

Figure 18. Electrode placement over belly of lateral triceps brachii.

Data Collection

All data was collected digitally (on software) through the interfaced components. The BIOPAC MP100 data acquisition and analysis system used the Acq*Knowledge* software to digitally record the sEMG signal, which was integrated and time synced with the E-Prime 2.0

software in order to combine the temporal measures of fractionated reaction time with the physiological measure of sEMG.

Measurement

The dependent measure of time was averaged per block to produce a mean reaction time (mRT), mean premotor time (mPMT), and mean motor time (mMT) to evaluate performance across blocks. mRT was the average time taken to initiate a physical response once the visual stimulus appeared, which represents the culmination of the mPMT and mMT. mPMT was the average time taken from stimulus onset to the firing of the muscle action potential, which represents central processing time. mMT was the average time from the appearance of the muscle action potential to the initiation of the physical response, which represents peripheral processing time. In equation form:

$$RT = PMT + MT$$

Where MT is subtracted from RT to obtain PMT.

RTs greater than 600 ms were assumed to indicate a lack of task vigilance, and MTs less than 20 ms or greater than 100 ms were assumed to indicate equipment error, and were omitted during data analysis.

This experiment used within-participant's and between-participant's designs, and the data from the subjects was characterized using descriptive data analysis. Four ANOVAs were generated to determine differences within and between groups. The Dependent Variables measured were RT, PMT, and MT. Means, standard deviations, and standard errors of the mean for each dependent measure were calculated. The Independent Variable was muscle size. The order of muscle size was counter-balanced across participants. A probability value of $p < 0.05$ was accepted as significant for differences. All statistical analyses were performed using SAS Version 9.2 (SAS Institutes, Inc., Cary, NC).

Results

For each condition, mean reaction time (mRT), mean premotor time (mPMT), and mean motor time (mMT) were calculated for each participant and evaluated employing four separate analyses of variance (ANOVAs). First, was a 2 (muscle size condition [small or large]) x 6 (blocks) ANOVA, with repeated measures on conditions and blocks. Second, was a 2 (muscle size group [small or large]) x 2 (sequence [1 or 2]) ANOVA between participant's design, where: Small-Group was made up of all APB blocks from all participants; Large-Group was made up of all LTB blocks from all participants; sequence1 was made up of blocks 1, 3, and 5 from all participants; sequence2 was made up of blocks 2, 4, and 6 from all participants. Third, was a 2 (sex [female or male]) x 2 (muscle size group [small or large]) ANOVA between participant's design. Fourth, was a 2 (relative-timing of muscle size condition [APB or LTB]) x 6 (blocks) ANOVA with repeated measures on conditions and blocks.

Muscle Size Condition and Blocks

Mean Reaction Time (mRT)

The analysis indicated that the main effect of muscle size condition, (small, $M = 215.55$; large, $M = 249.02$), $F(1, 20) = 62.95$, ($p<.0001$) with an R^2 of 1.0, was significant. Duncan's multiple range test on muscle size indicated that mRT was significantly shorter for the small muscle (see Figure 19). The main effect of block, $F(5, 80) = 3.74$, ($p=.0043$) was also significant. Duncan's multiple range test on blocks indicated that mRT was longer in block 1 than in all other blocks, and that there was no significant difference between blocks 2-6. No interaction existed.

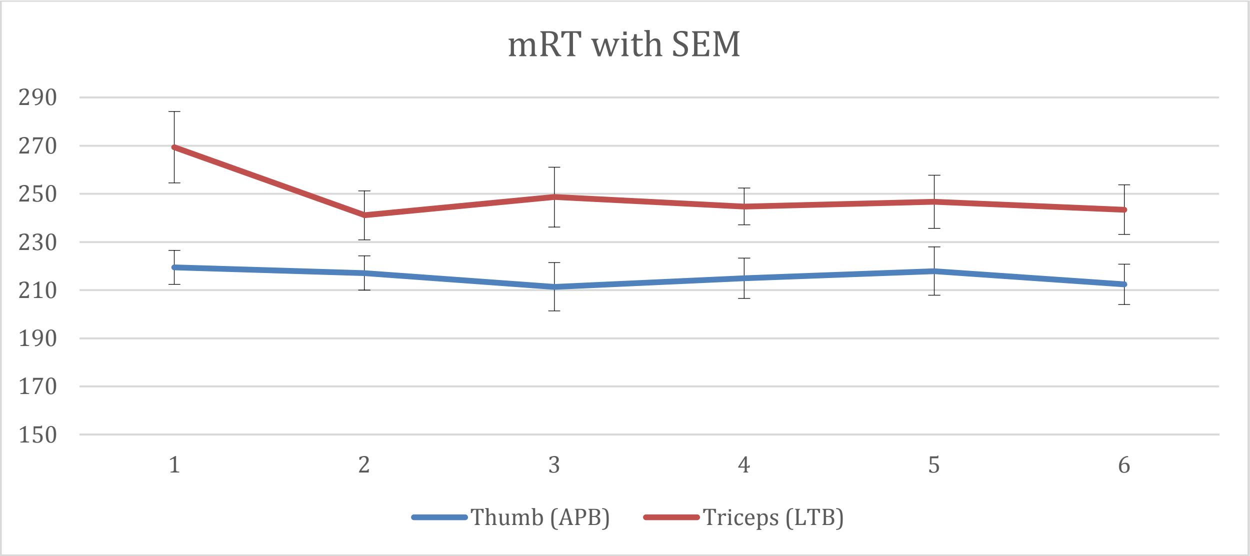

Figure 19. Mean reaction time with standard error of the mean across blocks maintaining counter-balanced design.

Mean Premotor Time (mPMT)

The analysis indicated that the main effect of muscle size condition, (small, *M* = 156.90; large, *M* = 169.19), *F*(1, 20) = 9.05, (*p*=.007) with an R^2 of 1.0, was significant. Duncan's multiple range test on muscle size indicated that mPMT was significantly shorter for the small muscle (see Figure 20). The main effect of block *F*(5, 80) = 4.61, (*p*=.001) was also significant. Duncan's multiple range test on blocks indicated that mPMT was longer in block 1 than in all other blocks, and that there was no significant difference between blocks 2-6. No interaction existed.

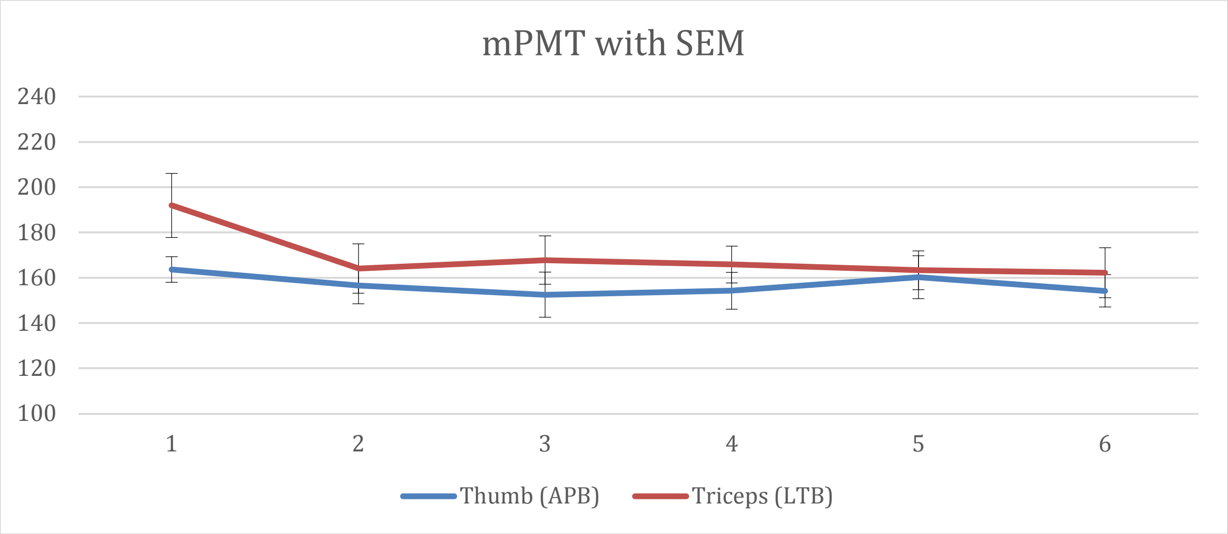

Figure 20. Mean premotor time with standard error of the mean across blocks maintaining counter-balanced design.

Mean Motor Time (mMT)

The analysis indicated that the main effect of muscle size condition, (small, *M* = 58.65; large, *M* = 79.83), *F*(1, 20) = 70.06, (*p*<.0001) with an R^2 of 1.0, was significant. Duncan's multiple range test on muscle size indicated that mMT was significantly shorter for the small muscle (see Figure 21). There was no significant main effect for block and no interaction existed.

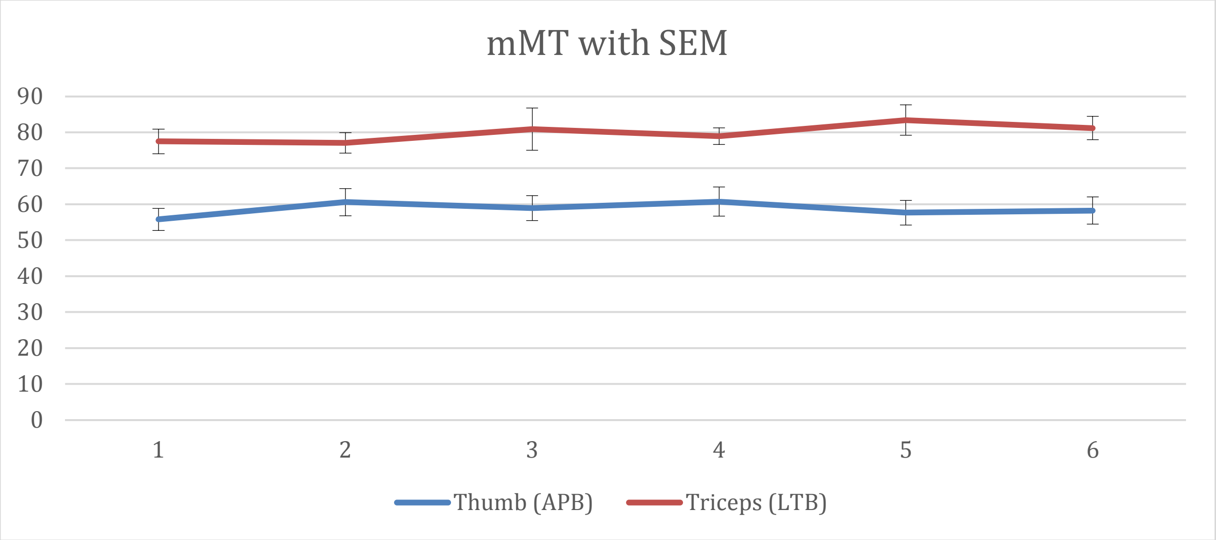

Figure 21. Mean motor time with standard error of the mean across blocks maintaining counter-balanced design.

Figure 22 demonstrates the real-time difference between a typical small and large muscle size trial. Reaction time, premotor time, and motor time for the small muscle (APB) trial was 193ms, 140ms, and 53ms, respectively. Reaction time, premotor time, and motor time for the large muscle (LTB) trial was 283ms, 205ms, and 78ms, respectively.

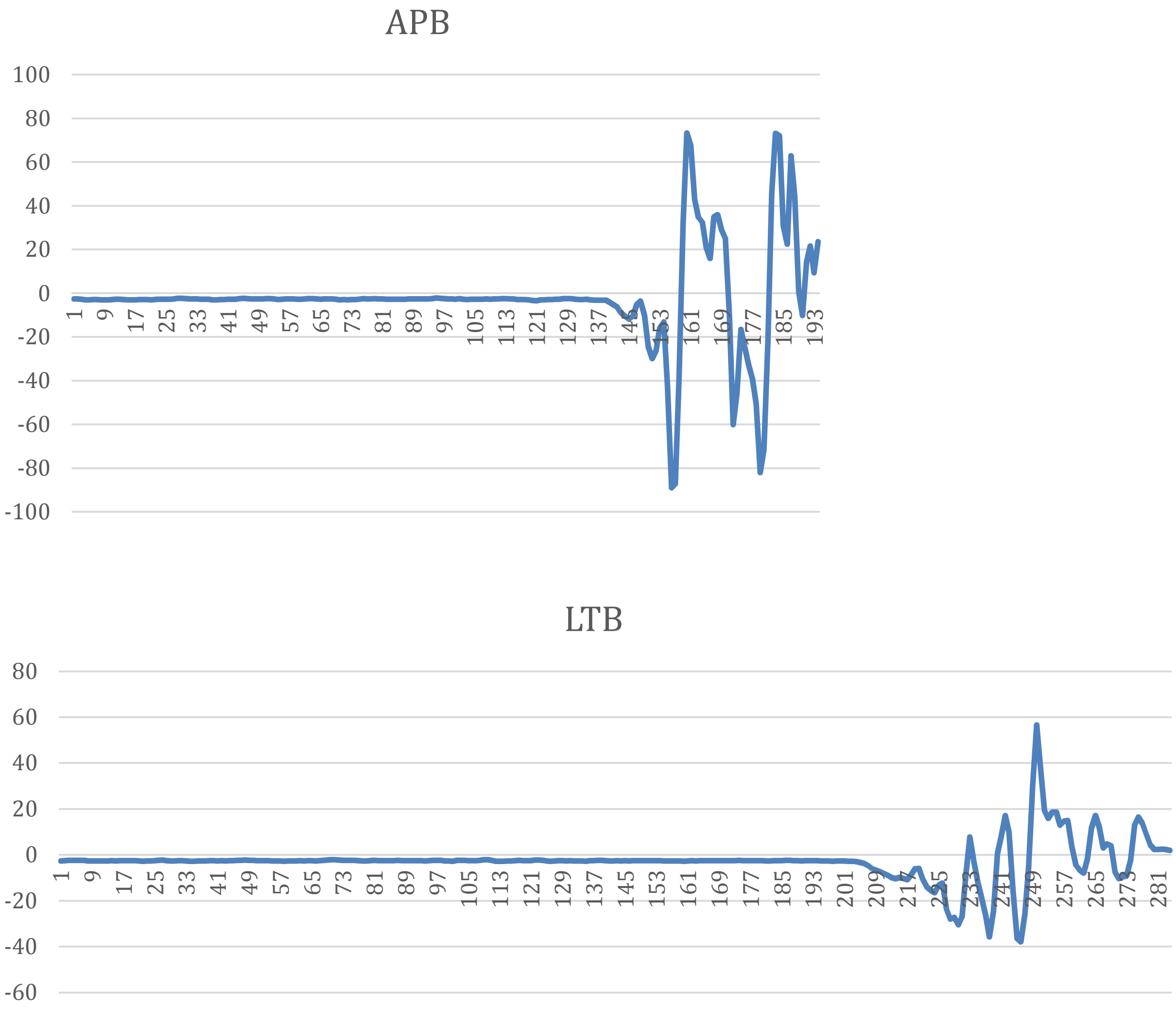

Figure 22. Time-matched comparison of typical performance between muscle size conditions.

Muscle Size Group and Sequence

In order to evaluate performance among all blocks of APB verses LTB for all participants, two muscle size groups were formed. All APB blocks comprised Small-Group, while all LTB blocks comprised Large-Group. In order to determine if the order in which the muscle size condition was presented had an effect on performance, two sequences were formed. Sequence1 represented all blocks numbered 1, 3, and 5, while sequence2 represented all blocks numbered 2, 4, and 6. The mean performance scores and associated standard error of the mean are presented in Table 3.

Mean Reaction Time (mRT)

The analysis indicated that the main effect of muscle size group, (small, $M = 215.55$; large, $M = 249.39$), $F(1, 128) = 34.38$, ($p<.0001$) with an R^2 of .22, was significant. Duncan's multiple range test on muscle size group indicated that mRT was significantly shorter for the Small-Group. There was no significant main effect for sequence and no interaction existed.

Mean Premotor Time (mPMT)

The analysis indicated that the main effect of muscle size group, (small, $M = 156.94$; large, $M = 171.05$), $F(1, 128) = 6.41$, ($p=.0125$) with an R^2 of .07, was significant. Duncan's multiple range test on muscle size group indicated that mPMT was significantly shorter for the Small-Group. There was no significant main effect for sequence and no interaction existed.

Mean Motor Time (mMT)

The analysis indicated that the main effect of muscle size group, (small, $M = 58.61$; large, $M = 78.34$), $F(1, 128) = 109.48$, ($p<.0001$) with an R^2 of .46, was significant. Duncan's multiple range test on muscle size group indicated that mMT was significantly shorter for the Small-Group. There was no significant main effect for sequence and no interaction existed.

Table 3: The Mean Performance Scores and ± SEM of RT, PMT, and MT for the Muscle Size Group X Sequence Order Interaction.

	Group (RT)		Group (PMT)		Group (MT)	
	1	2	1	2	1	2
S1	216.26 ± 5.15	255.96 ± 7.66	158.80 ± 4.87	177.82 ± 7.03	57.46 ± 1.87	78.13 ± 2.01
S2	214.83 ± 4.47	242.82 ± 5.32	155.08 ± 4.37	164.28 ± 5.66	59.75 ± 2.14	78.54 ± 1.44

* $P < 0.05$

Muscle Size Group and Sex

Mean Reaction Time (mRT)

The analysis indicated that the main effect of sex, (female, $M = 245.29$; male, $M = 219.64$), $F(1, 128) = 23.15$, ($p<.0001$) with an R^2 of .34, was significant. Duncan's multiple range test on sex indicated that mRT was significantly shorter for males. The main effect of muscle size group, (small, $M = 215.55$; large, $M = 249.39$), $F(1, 128) = 40.30$, ($p<.0001$) was also significant. Duncan's multiple range test on muscle size group indicated that mRT was significantly shorter for the Small-Group. No interaction existed.

Mean Premotor Time (mPMT)

The analysis indicated that the main effect of sex, (female, $M = 175.91$; male, $M = 152.09$), $F(1, 128) = 20.98$, ($p<.0001$) with an R^2 of .19, was significant. Duncan's multiple range test on sex indicated that mPMT was significantly shorter for males. The main effect of muscle size group, (small, $M = 156.94$; large, $M = 171.05$), $F(1, 128) = 7.36$, ($p=.0076$) was also significant. Duncan's multiple range test on muscle size group indicated that mPMT was significantly shorter for the Small-Group. No interaction existed.

Mean Motor Time (mMT)

The analysis indicated that the main effect of sex was not significant. The main effect of muscle size group, (small, $M = 58.61$; large, $M = 78.34$), $F(1, 128) = 109.88$, ($p<.0001$) with an R^2

of .46, was significant. Duncan’s multiple range test on muscle size group indicated that mMT was significantly shorter for the Small-Group. No interaction existed. The mean performance scores and associated standard error of the mean are presented in Table 4.

Table 4: The Mean Performance Scores and ± SEM of RT, PMT, and MT for the Sex X Muscle Size Group ANOVA.

	Group (RT)		Group (PMT)		Group (MT)	
	Small	Large	Small	Large	Small*	Large
Female	224.62 ± 5.66	265.96 ± 7.93	165.61 ± 5.37	186.21 ± 7.75	59.01 ± 1.62	79.76 ± 1.50
Male	206.47* ± 3.04	232.81* ± 3.10	148.27* ± 3.08	155.90* ± 3.15	58.20 ± 2.36	76.91 ± 1.94

* $P < 0.05$

Muscle Size and Relative-Timing of Reaction Time Components

Mean Ratio of Premotor Time (mrPMT) to Total Reaction Time

The analysis indicated that the main effect of muscle size condition, (small, $M = 72.04$; large, $M = 67.06$), $F(1, 20) = 20.08$, (p=.0002) with an R^2 of 1.0, was significant. Duncan’s multiple range test on muscle size indicated that the small muscle had a significantly greater percentage of time spent in PMT than the large muscle (see Figure 23). The main effect of block $F(5, 80) = 3.84$, (p=.0036) was also significant. Duncan’s multiple range test on blocks indicated that mrPMT was longer in block 1 than in all other blocks, and that there was no significant difference between blocks 2-6.

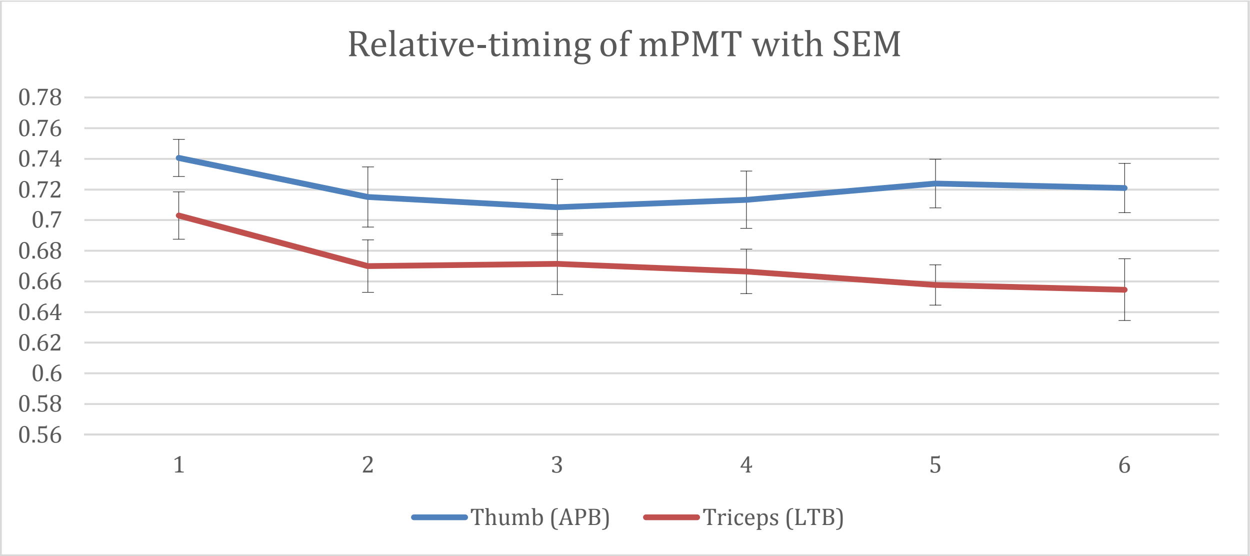

Figure 23. Relative-timing of mPMT with standard error of the mean between muscle sizes.

Mean Ratio of Motor Time (mrMT) to Total Reaction Time

The analysis indicated that the main effect of muscle size condition, (small, *M* = 27.96; large, *M* = 32.95), *F*(1, 20) = 20.08, (*p*=.0002) with an R^2 of 1.0, was significant. Duncan's multiple range test on muscle size indicated that the large muscle had a significantly greater percentage of time spent in MT than the small muscle (see Figure 24). The main effect of block *F*(5, 80) = 3.84, (*p*=.0036) was also significant. Duncan's multiple range test on blocks indicated that mrMT was longer in block 1 than in all other blocks, and that there was no significant difference between blocks 2-6.

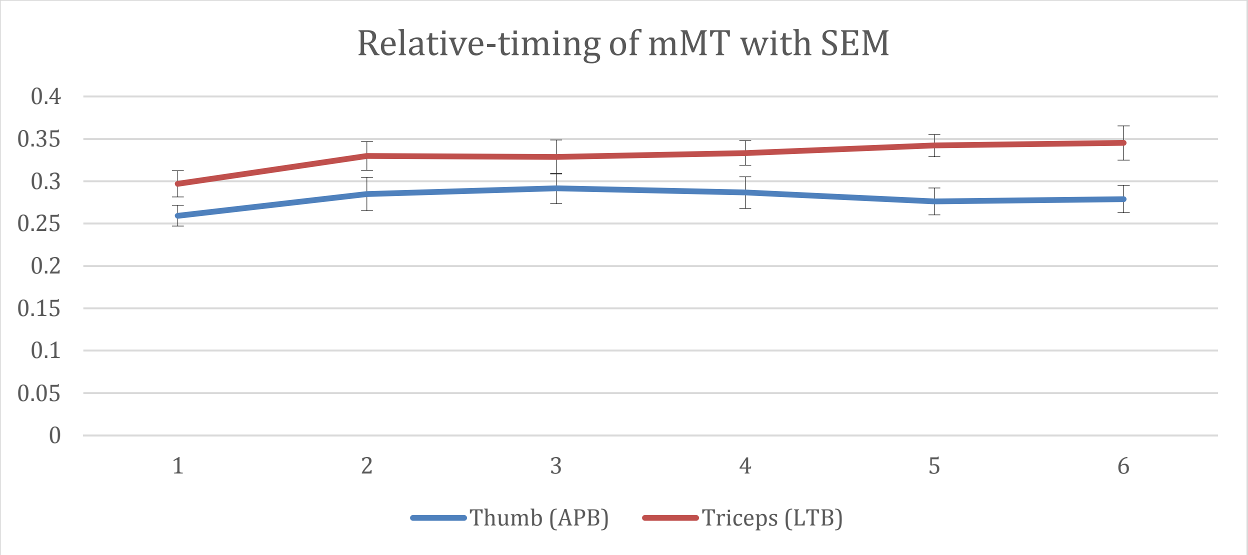

Figure 24. Relative-timing of mMT with standard error of the mean between muscle sizes.

Summary

As predicted, the within-participant's analysis of the muscle size condition and block indicated that mRT and mMT were significantly shorter in the small muscle. Unexpected, was the finding that mPMT was also significantly shorter in the small muscle. In further contradiction with the hypotheses, was that mRT did not progressively decrease across blocks, with mRT and mPMT longer in block 1 than in all other blocks, and no significant difference between blocks 2 through 6. These findings were followed with non-significance for an observed mMT across blocks as well. The observed plateau in mRT across the majority of blocks may have been due to the counter-balanced design. Further, there was no significant interaction between the muscle size condition and block.

Two muscle size groups were created in order to compare all APB verses LTB blocks, named Small-Group and Large-Group, respectively. Additionally, two sets of sequence were created in order to compare the effect of condition ordering in the counter-balanced design. Sequence1 represented all blocks numbered 1, 3, and 5, while sequence2 represented all blocks numbered 2, 4, and 6. The between-participant's analysis of muscle size group and sequence indicated that mRT, mPMT, and mMT were significantly shorter in the Small-Group. There were no significant differences between sequences, and there were no significant interactions between muscle size group and sequence.

The between-participant's analysis of sex and muscle size group indicated that mRT and mPMT were significantly shorter for males, but no significant difference was demonstrated in mMT for sex. This interesting finding indicates that males are more efficient at information processing than females when the task requires alternating muscle size by block. The analysis also indicated that mRT, mPMT, and mMT were all significantly shorter in the Small-Group. There were no significant interactions between muscle size group and sex.

Finally, the within-participant's analysis of the muscle size condition and block indicated a relative-timing difference between the large and small muscles. A greater percentage of time was spent in peripheral processing for the large muscle compared to the small, which is evidence in opposition to the notion of effector independence in the GMP.

CHAPTER 5: GENERAL DISCUSSION

The primary objectives of this study were to determine the effects of foreperiod regularity and muscle size on the central (PMT) and peripheral (MT) components of fractionated reaction time. For this purpose, two different types of software (E-Prime 2.0 and AcqKnowledge) were programed to fully integrate, allowing for millisecond timing precision and temporal syncing of the reaction time (RT) and surface electromyographic (sEMG) data. This study is the first that the author is aware of having done so. The results suggest effects of foreperiod regularity on central processing, interaction effects with sequence, muscle size effects on central and peripheral processing, effector-dependence, and sex differences. Each of those findings will be considered in the following sections.

Foreperiod Condition

Dr. Alfred Weiss was the first to fractionate reaction time into central (PMT) and peripheral (MT) processing times (Weiss, 1965). Simply, factors thought to confuse or require a higher level of attention would seemingly have an effect on PMT, while those variables related specifically to the agonist muscle(s) would have an effect on MT. As predicted, mRT and mPMT were significantly shorter in the regular foreperiod blocks compared to the irregular foreperiod blocks, with no meaningful difference in mMT, which agrees with previous findings (Kawama, 1996; Botwinick & Thompson, 1966a, 1966b; Weiss, 1965).

Nissen and Bullemer (1987) showed that reaction time decreases with learning if the stimulus is presented in a predictable manner. The irregular foreperiod disallows the participant to, with sufficient accuracy, correctly predict the stimulus onset. With predictability being low, the participants had to wait until they detected the stimulus to move through each of the information processing stages to respond, hence the increased latency observed in the mRT and mPMT for the irregular foreperiod blocks. Within a regularly repeating foreperiod paradigm, the internal representation of the temporal relationship from the beginning of the foreperiod (yellow orb) to the stimulus (green orb) is strengthened, which is manifest by faster reaction times during the regular foreperiod blocks. Kandel, Kupfermann, & Iversen (2000) speculate the brain may have evolved to associate events that occur predictably with other stimuli, versus unreliably and random, as a successful solution for adapting to our environment (i.e., selecting nutritious vs. poisonous food). These causal relationships formed by the associative learning between two stimuli, as is the case with the foreperiod signal and the predictability of the stimulus onset, may be further support for the shorter latencies observed with the regular foreperiod blocks.

Faster reaction times were observed in the regular foreperiod blocks presumably due to the ability of the nervous system to keep the motor program at-the-ready (working memory) to send as soon as the stimulus was identified. Kerr (1978) suggested that it was possible for both response selection and response programming to occur prior to stimulus onset. Additionally, Eccles (1986) proposed that the supplementary motor area is responsible for preparatory development of the motor program (response selection). That information would be sent to the premotor area to complete the motor programming process where it could also store the motor program, which would then be transferred to the motor cortex and descending pathway to the responding musculature.

Conversely, the motor program would not be allowed to remain on stand-by in the irregular foreperiod blocks because of an inability to correctly anticipate the stimulus onset, and without a developing temporal relationship, no associative learning would transpire, hence the slower reaction times. Although Jacobsen and Nissen (1937) were incorrect regarding the type of memory affected (short-term), they were the first to demonstrate that the prefrontal cortex was involved with memory and planning of motor actions. Jacobsen's research was later enhanced by Baddeley (2003) whom introduced the notion of working memory, which is a form of motor planning and refers to the active maintenance of information relevant to an ongoing behavior. This is supported by a primary function of Brodmann's area 46 of the prefrontal cortex in sending information mostly to the ventral premotor area and playing an integral role in working memory. Further, the adjacent lateral dorsal premotor area is involved in learning to associate a particular sensory event with a specific movement (associative learning). This proximal and integrative configuration seems likely to increase efficiency in central processing speed. The physical response remained unchanged across blocks, as such, I did not expect or observe a significant change in mMT.

In contrast to one of the hypotheses, was that mRT did not significantly decrease with practice across blocks. The lack of continued performance betterment may have been due to one or a combination of the following; (1) existence of a priming effect, (2) a practice effect, (3) and or alternating of the foreperiod regularity by block.

Priming is a phenomenon in which recognition of an object improves with subsequent encounters with that object (Tulving & Schacter, 1990; Schacter & Buckner, 1998). The simplicity of the simple reaction time task (no choice alternatives paired with a consistent stimulus) could be responsible for the quick performance increase observed by the second block of trials. Also, this inherent simplicity may explain the quick plateau in performance, as a ceiling effect of nothing further to learn or allow additional benefits from more efficient information processing. In more complicated reaction time (choice RT) or recognition tasks (facial recognition), priming will enhance recognition by pruning other possible alternatives, while also decreasing but strengthening the selected neurons conveying information for the primed object, titled 'repetition suppression" (Rainer & Miller, 2000; Li, Miller, & Desimone, 1993; Demb et al., 1995; Buckner et al., 1998). Further, Bar (2003) concluded that priming may act to automatize processing through neural modifications of the most likely object representation, thereby accelerating central processing speed. Likewise, neurophysiological support for this notion was demonstrated by Rainer and Miller (2000) who found that repetition suppression of prefrontal cortex response to visual stimuli is directly correlated with improved performance. Additionally, as a progressive and integrative sequence, it seems that priming may allow for enhanced visiomotor coupling by maintaining an appropriate level of attention (lacking decay) for working memory and therefore allows associative learning to happen at an accelerated rate.

While many have found practice to significantly decrease RT (Ando, Kida, & Oda, 2002; Aiken & Lichtenstein, 1964; Norrie, 1967; Taniguchi, 1999; Mowbray & Rhoades, 1959), a few have not (Georgopoulos, Kalaska, & Massey, 1981). The reasoning for the limited improvement demonstrated in this experiment may simply be a result of the participants having had no previous experience with the RT task, also reported by Weiss (1965), and the effects of practice (increased comfortability with the task) may be responsible for the initial improvement but quick plateau thereafter.

Lastly, alternating foreperiod regularity by block may have hindered a performance enhancement across blocks because of contextual interference of high and low predictability of stimulus onset. Several studies (Klemmer, 1956; Karlin, 1959; Kawama, 1996; Drazin, 1961; Gordon, 1967) have demonstrated the beneficial and detrimental effects of foreperiod regularity and irregularity. This is supported by the contextual interference literature (Batting, 1966, 1972, 1979; Shea & Morgan, 1979; Magill & Hall, 1990; Immink & Wright, 1998, 2001), which demonstrates an impairment in acquisition performance during high contextual interference (irregular foreperiod blocks) compared to low contextual interference (regular foreperiod blocks).

Taken together, the counter-balanced design used here may have led to an inability for the participants to improve processing speed across blocks because of too regular a shift from low to high predictability of stimulus onset from block to block. No significant interaction existed between either foreperiod condition and blocks.

Groups and sequences were formed as previously detailed. A foreperiod-group X sequence ANOVA was analyzed based on the premise that the counter-balanced design of the study may have exerted an effect on the participants' mRT performance across blocks. As expected, the mRT was significantly shorter in the Reg-Group compared to the IRreg-Group and this was due to a shorter mPMT, with no appreciable difference in the mMT between groups. Interestingly, a significant interaction between foreperiod-group and sequence for mRT and mPMT arose. Specifically, the participants who initiated testing with the regular foreperiod block produced the shortest mRT and mPMT while the participants who initiated testing with the irregular foreperiod block produced the longest mRT and mPMT. This interaction demonstrates that the effect sequence has, can change, depending on the foreperiod-group. This interaction is presumably the consequence of contextual interference because of the significant sway in performance observed between those beginning with either a regular or irregular foreperiod block. Functionally, beginning with an irregular foreperiod block, opposed to a regular foreperiod block, interferes with the ability to develop an adaptable strategy to contend with alternating blocks of irregular and regular foreperiods. As this study did not measure retention, it remains to be seen if the impact observed here from sequence order would ultimately benefit or continue to impair performance in a simple reaction time task. No significant interaction existed for mMT.

Muscle Size Condition

Dimensions of the body segments in adult men and women have been determined utilizing gamma-scanning procedures (Zatsiorsky & Seluyanov, 1983; Zatsiorsky, Seluyanov, & Chugunova, 1990), which were later refined by de Leva (1996) using joint centers as reference points for accuracy, and are listed in table 5.

Table 5: Segment Length and Mass for Young Adult Women (W) and Men (M).

	Length (cm)		Mass (%)	
Segment	W	M	W	M
Upper arm	27.51	28.17	2.55	2.71
Forearm	26.43	26.89	1.38	1.62
Hand	7.80	8.62	0.56	0.61

In relation to the body segment, is the size of the muscle(s) that are responsible for generating sufficient force to rotate each segment for movement to occur. Physiological cross sectional area (PSCA) of the triceps brachii (23.8 cm^2) was obtained from cadavers (Edgerton, Apor, & Roy, 1990), and Mohseny et al. (2015), using ultrasound measurements, reported 1.14 cm^2 for the APB. Cavanaugh & Komi (1979) stated that within the processes of the EMD, stretching of the series elastic component occupies the largest amount of time. It then stands to reason that a larger muscle would not only be responsible for moving a larger body segment, but also have a thicker tendon (Loren & Lieber, 1995), which would take longer for the contractile component to stretch the aponeurosis and tendon before movement could occur. It has also been demonstrated that muscle strength is correlated with the elastic properties of the tendon (Muraoka, Muramatsu, Fukunaga, & Kanehisa, 2005). Monster, Chan, & O'Connor (1978) demonstrated that smaller muscles have a greater density of type I muscle fibers, with the abductor pollicis brevis having 63% and the triceps brachii having a range of 33-50%, with Harridge and colleagues (1996) supporting this work by finding the triceps brachii to contain 33% type I myosin heavy chain isoform. Further, as the size principle (Henneman, 1957) states, motor units are recruited in order of increasing size. Since small muscles have a greater density of small motor neurons, they will be recruited prior to large muscles with larger motor neurons. Thus, it is logical to understand why smaller muscles can respond faster than large muscles when resistance is minimal.

As predicted, mRT and mMT were significantly shorter in the small muscle (APB). Unexpectedly, the results also showed mPMT to be significantly shorter in the APB and this may have been due to a more complicated movement (Henry & Rogers, 1960; Christina, 1985) or neuroanatomical organization. Even though the shoulder was in a neutral position, there may have been a slight shoulder depression initiating the kinetic chain to elbow extension and finishing with a stiffening of the wrist in preparation of bottoming-out of the response pedal caused by the rapid impulse downward. The longer motor program would then involve multiple joints, muscle synergies, and greater overall passive tension in the involved tissues, all accounting for the longer latency in the triceps brachii.

Another possibility of the increased latency in the PMT of the triceps may have been due to the somatotopic organization of the muscles in the primary motor cortex. The hand and fingers represent a considerably larger area of the motor cortex compared to the elbow because of the higher level of control required for intricate manual dexterity tasks. Therefore, the elbow may take more processing time because there is less cortical area specifically designated to it. Additionally, there are premotor neurons that form direct monosynaptic highways with the hand, which may have the potential to activate the musculature without the involvement of the primary motor cortex (Krakauer & Ghez, 2000). If so, this shortcut may further explain the faster response times with the small muscle of the thumb.

Further, similar to that observed in experiment one, mRT did not progressively decrease with practice across blocks. The mRT and mPMT were longer in block 1 compared to the rest of the blocks, with no significant time difference between blocks 2 through 6, along with no significant change in mMT across all blocks. Having the same general pattern of a performance plateau across blocks in both experiments leads this author to reason the same as for experiment one. Briefly, that (1) there may have been a priming effect in the first block in which the participants became quickly acclimated to the task with performance improvements observed by the second block, but with no significant timing difference thereafter. (2) More practice trials may have yielded a decrease in RT latency. (3) Alternating the muscle size by block may have hindered a performance enhancement across blocks because of contextual interference with mode of response. Additionally, no significant interaction existed between muscle size and block.

Groups and sequences were formed as previously detailed. A muscle size group X sequence ANOVA was analyzed based on the premise that the counter-balanced design of the study may have exerted an effect on the participants' mRT performance across blocks. As expected, the mRT, mPMT, and mMT were significantly shorter in the Small-Group. Unlike experiment one, there were no significant differences between sequences and no significant interaction existed. Although all three of the time variables were significantly shorter in the Small-Group, the lack of a sequence effect on the muscle size groups may have been due to a comparative lack of complexity compared with experiment one. The regular foreperiod administered for all trials potentially allowed the factor of central processing complexity to approach a baseline rather quickly (within the first block), as the temporal presentation of the stimulus was presumably implicitly learned.

Given that both mPMT and mMT were significantly longer during the LTB blocks, it seemed prudent to examine the inter-effector timing proportions of the FRT components. To test this, the ratios of mPMT to mRT and mMT to mRT for both APB and LTB muscles were calculated. Schmidt (1976) hypothesized that the invariant features (relative-timing, relative force) are structured in the motor program and that the superficial movement elements (muscles used, speed) are the program parameters. Specifically, effector-independence is an assumed element of the abstract motor program, in which the same order of events will occur, invariantly, with the same relative timing pattern, regardless of the muscles or joints involved in the task.

While several authors have provided convincing evidence for effector-independence utilizing sequential timing tasks (Lai, Shea, Wulf, & Wright, 2000; Lai & Shea, 1998, 1999; Blandin, Lhuisset, & Proteau, 1999; Badets & Blandin, 2004; Black & Wright, 2000; Wulf, Lee, & Schmidt, 1994,), sequential finger movements (Japikse, Negash, Howard, & Howard, 2003), ball catching (Morton, Lang, & Bastian, 2001), visiomotor rotations (Sainburg & Wang, 2002), and inter-limb reaching (Criscimagna-Hemminger, Donchin, Gazzaniga, & Shadmehr, 2003), the results from this study challenge the GMP theory by demonstrating effector-dependence. For example, Lai & Shea (1998) instructed participants to sequentially press four keys (in order; 2, 4, 8, and 6) with the index finger of their right hand on the number keypad of a computer keyboard. There were three total movement time versions (A, 700; B, 900; C, 1,100 ms) that they were asked to complete the sequence in, while maintaining a relative-timing goal for each segment of 22.2% (key 2 to 4), 44.4% (key 4 to 8), and 33.3% (key 8 to 6). Regardless of the absolute timing goal, the relative timing goal did not vary across trials. Here, the participants were to learn a specified proportion of movement time between segments, which they were able to do and maintain for all absolute timing task versions. Those results provide evidence that relative-timing is part of the GMP. However, the participants were provided with feedback of their relative-timing performance, which presumable allowed them to develop a cognitive strategy to learn the appropriate temporal pattern. Since the ratio from segment-to-segment was learned under specific task guidelines in the laboratory, I question those findings as valid support for effector-independence.

On the other hand, the present study did not have a sequential relative-timing task, as the participants were merely instructed to respond as rapidly as possible once they detected the imperative stimulus. The results from this experiment showed that there was a significant difference in mPMT and mMT proportions between the APB and LTB. To respond, the muscular actions for the thumb and triceps were classified as flexion/opposition and extension, respectively. The movement of the thumb was virtually identical to that of texting on a cell phone or button press on any video game controller. The typical gaming system controllers' physical configuration is such that the left-hand thumb manipulates directional control, while the right-hand thumb presses action buttons. Although motor transfer is not well understood (Schmidt & Young, 1987), the ubiquitous theme in the transfer literature is similarity (or lack of) between the two movements or skills being compared, with high similarity equaling high transfer. Given the likeliness of a positive transfer effect for these highly similar and well-practiced movements, it seems unlikely that the difference in relative-timing between the two muscles is due to novelty, as the same behavior class of action should have the same GMP. Though, the notion of transfer may not be well understood in the motor behavior arena, there is more support for this idea in exercise and sport science known as training specificity. For example, isometric versus dynamic resistance training will each improve strength, however, the strength gained is highly specific to the range of motion trained in and the speed with which the contractions occurred, and those strength enhancements have limited transferability to the other type of training (Barak, Ayalon, & Dvir, 2004; Duchateau & Hainaut, 1984; Graves, Pollock, Jones, Colvin, & Leggett, 1989). Theoretically, it is possible that the hand may have a unique set of GMP's relative to the rest of the body because of the significantly greater cortical area designated to it. If so, there would be different GMP's for the APB and LTB, which would, at least in part, explain the difference in their relative-timing, however, this remains to be determined.

Based on the previous literature supporting effector-independence as a built-in element of the abstract motor program, the change in muscle size, which is categorized as a parameter of the GMP, should not have had an impact on the relative-timing. The action of behavior was the same under both muscle size conditions, where the key under the thumb and the footswitch under the palm needed to be pushed down. This same action of behavior presumably would employ the same motor program and should therefore maintain the invariant feature of relative-timing, regardless of the variant feature (muscle selection) chosen. Further, relative-timing should have remained stable as the opportunity to select any muscle within the same behavior class would inherently welcome different size muscles (small vs. large) and their respective muscular actions (flexion vs. extension). However, the results from this study do not support this claim. The observed inconsistency in relative-timing between muscle sizes with the same action of behavior and within the same limb provides evidence for effector-dependence, as these results indicate the GMP model does not consistently predict effector-independence.

Sex Differences

Overall, studies reporting sex differences in reaction time performance are inconsistent. While some research shows no sex difference (Woods, Wyma, Yund, Herron, & Reed, 2015; Der & Deary, 2006; Gottsdanker, 1982; Annett & Annett, 1979) others report shorter times for men (Anstey, Dear, Christensen, & Jorm, 2005; Dykiert, Der, Starr, & Deary, 2012; Fittro, Bolla, Heller, & Meyd, 1992). Further, Reimers & Maylor (2006) observed a reduction in sex differences as the participants became more familiar with the task and concluded that differences may fade altogether with greater practice.

The results from experiment one failed to show a significant difference in mRT between sexes, though there was a trend for females to respond faster. However, females demonstrated a significantly shorter mPMT than their male counterparts. This finding indicates that females are more efficient at information processing than males when the task requires alternating the foreperiod condition by block. A small amount of literature lends some support for this finding in college women (Wrisberg & Ragsdale, 1979) and first-grade girls (Allen, 1978), both demonstrating that females were able to benefit more from practice variability then males. These results imply a potential sex bias where women outperform men in situations where task change is frequent and at least mildly uncertain. No significant interactions existed nor did mMT reach significance between sexes.

In experiment two, on the other hand, mRT and mPMT were significantly shorter for males, though there was no significant sex difference in mMT. This indicates that males are more efficient at information processing than females when stimulus onset is predictable and the task requires alternating muscle size frequently. The analysis also indicated that mRT, mPMT, and mMT were all significantly shorter in the small muscle group. There were no significant interactions between muscle size group and sex.

Collectively, females outperformed males when predictability fluctuated, and males outperformed females when required to switch between intra-limb muscles of different size. This alludes to a possible positive cognitive transfer for females but negative cognitive transfer for males in experiment one, and a positive motor transfer for males but negative motor transfer for females in experiment two. These findings indicate there may be a sex specific central processing mechanism of interference, which may lead to future research in this area.

Limitations

Because this research focused on within-participant's comparisons of reaction time performance, muscular strength, video game usage, and caffeinated drinks were not controlled for. Though, it is recommended that future researchers consider these perceived limitations in their study design and the potential impact they may have on their conclusions.

Resistance training has been shown to increase muscle strength, volume, stiffness of the muscle-tendon complex, rate of torque development, and decrease electromechanical delay (Kubo, Kanehisa, Ito, & Fukunaga, 2001; Kubo, Kanehisa, Kawakami, & Fukunaga, 2000; Narici, et al., 1996; Wilson, Murphy, & Pryor, 1994). The results from these studies suggest a trained muscle is more efficient at producing movement versus an untrained muscle, regardless of its larger size, resulting in faster reaction times. Since the participants were recruited from Kinesiology classes, bias may have been introduced into the sample because of the potential for these males to have greater upper-body strength compared to males in other majors overall, and to females specifically. Therefore, it is recommended that a baseline level of strength be determined along with an understanding of the participants' physical activity over the previous three months.

The video game industry occupies a large portion of digital media with dollar sales in the billions (Vorderer & Bryant, 2006). However, a significant difference exists in game play among the sexes (Ivory, 2006), with females demonstrating less overall interest, lower frequency of play, and playing for shorter periods of time (Lucas & Sherry, 2004; Wright, et al., 2001). Given these findings, it may be worthwhile to pre-screen participants for time spent gaming as there could be a considerable practice effect, specifically with eye-hand coordination favoring faster reaction times for males. Additionally, a high level of proficiency in texting may translate to a response advantage similar to that observed in a trained (versus untrained) muscle.

Determining the level of caffeine ingestion (chronically and acutely) of the participants may improve the validity of the data collected. Caffeinated drinks (e.g. energy drinks, coffee) are popular among college students, typically reporting consumption to increase energy, alertness, and help finish their school work (Attila & Cakir, 2011; Malinauskas, Aeby, Overton, Carpenter-Aeby, & Barber-Heidal, 2007). However, since these drinks are so popular, attempting to control for usage (e.g. no caffeine for 12 hours prior to testing) may still confound results as the participant could then be in caffeine withdrawal, which could negatively affect their cognitive performance and overall mood, (James & Rogers, 2005) potentially skewing the results.

Given these limitations, future research should aim to include a pre-participation questionnaire addressing these concerns to form a basis for inclusion/exclusion criteria and categorization of participants.

Summary

The results of the initial analysis were in agreeance with a primary hypothesis, showing mRT and mPMT were significantly shorter in the regular compared to the irregular foreperiod blocks, with mMT remaining relatively unchanged. Further in line with prediction, was the finding that mRT and mMT were significantly shorter in the small muscle. Unanticipated however, was the finding that mPMT was also significantly shorter in the small muscle, which may be cause for future investigation. Further, the relative-timing analysis demonstrated a discrepancy between muscle sizes, supporting effector-dependence and opposing part of the GMP theory.

When comparing groups with sequences, mRT was significantly shorter with a regular versus an irregular foreperiod. Additionally, an interaction demonstrated that the participants who began testing with an irregular foreperiod were slowest to initiate a response, while those beginning with a regular foreperiod were fastest. Also, the mRT, mPMT, and mMT were significantly shorter in the small compared to the large muscle.

Finally, a supplementary analysis was conducted to determine if there was a performance difference between the sexes. Within the context of temporal uncertainty of a visual stimulus in a simple reaction time task, females demonstrated a greater ability to process the sensory information and initiate a physical response. On the other-hand, when the visual stimulus occurred at a regular interval, males demonstrated a greater ability to process the sensory information and initiate a physical response. In light of these findings, future FRT research should be aimed toward muscle size and sex differences of the lower extremity muscles, as well as the effect of sequence order of condition on skill acquisition, retention, and transfer.

APPENDIX: APPROVALS AND FRT INSTRUCTIONS

WAYNE STATE UNIVERSITY

IRB Administration Office
87 East Canfield, Second Floor
Detroit, Michigan 48201
Phone: (313) 577-1628
FAX: (313) 993-7122
http://irb.wayne.edu

NOTICE OF EXPEDITED APPROVAL

To: Ronald Benedict
Kinesiology, Health and Sport Studies
From: for Dr. Deborah Ellis or designee M. Campbell / 22
Chairperson, Behavioral Institutional Review Board (B3)
Date: December 09, 2015
RE: IRB #: 111815B3E
Protocol Title: Effects of Foreperiod Regularity and Muscle Size on Fractionated Reaction Time
Funding Source:
Protocol #: 1511014461
Expiration Date: December 08, 2016
Risk Level / Category: Research not involving greater than minimal risk

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The above-referenced protocol and items listed below (if applicable) were **APPROVED** following *Expedited Review* Category (#4)* by the Chairperson/designee *for* the Wayne State University Institutional Review Board (B3) for the period of 12/09/2015 through 12/08/2016. This approval does not replace any departmental or other approvals that may be required.

- Revised Protocol Summary Form (revision received in the IRB office 12/7/15)
- Revised Research Protocol (received in the IRB office 12/7/15)
- Medical records are not being accessed therefore HIPAA does not apply
- Behavioral Research Informed Consent (revision dated 12/7/2015)
- Recruitment Script

- Federal regulations require that all research be reviewed at least annually. You *may* receive a *"Continuation Renewal Reminder"* approximately two months prior to the expiration date; however, it is the Principal Investigator's responsibility to obtain review and continued approval ***before*** the expiration date. Data collected during a period of lapsed approval is unapproved research and can never be reported or published as research data.
- All changes or amendments to the above-referenced protocol require review and approval by the IRB **BEFORE** implementation.
- Adverse Reactions/Unexpected Events (AR/UE) must be submitted on the appropriate form within the timeframe specified in the IRB Administration Office Policy (http://www.irb.wayne.edu//policies-human-research.php).

NOTE:

1. Upon notification of an impending regulatory site visit, hold notification, and/or external audit the IRB Administration Office must be contacted immediately.
2. Forms should be downloaded from the IRB website at **each** use.

*Based on the Expedited Review List, revised November 1998

Behavioral Research Informed Consent

Title of Study: *Effects of Foreperiod Regularity and Muscle Size on Fractionated Reaction Time.*

Principal Investigator (PI):	Ronald Joseph Benedict Jr. Kinesiology, Health and Sport Studies (313) 577-4246

Purpose

You are being asked to be in a research study involving the factors that may have an effect on the components of reaction time because you are a student at Wayne State University, meet the required age range (19-30 years), and are healthy. This study is being conducted at Wayne State University in the Motor Behavior Laboratory, room 10 in Old Main. The estimated number of study participants to be enrolled at Wayne State University is about 60. **Please read this form and ask any questions you may have before agreeing to be in the study.**

Study Procedures

If you agree to take part in this research study, you will be participating in one of two different experiments.

In this research study, we will use a response switch to measure the speed of your reaction time to a visual stimulus (green orb). We will also measure the electrical activity in the muscles (sEMG) of your thumb and back of the upper arm (triceps) at the same time. These measures are of interest to us because we believe the information gained through this research will provide us with a greater understanding of the conditions that have an effect on the speed at which a person recognizes a stimulus and how quickly they can respond.

Experiment 1: All participants will complete six blocks of twelve trials, alternating the foreperiod (regular or irregular) condition for each block (e.g. Block 1 will have a regularly occurring foreperiod for all trials in blocks 1, 3, and 5. Block 2 will have four unique foreperiods that will be equally and randomly generated for all trials in blocks 2, 4, and 6). The order of foreperiod condition will be counterbalanced from participant to participant. The foreperiod is the time between the 'ready' signal and the presentation of the 'go' signal. The regular foreperiod set will last 2.5 seconds for each trial. The irregular foreperiod set will randomly occur at either 1, 2, 3, or 4 seconds duration to keep the participant from getting used to when the 'go' signal will appear.

Experiment 2: Each participant will alternate muscle groups for each block and complete six blocks of twelve trials with a regular foreperiod condition for all blocks. The order of which muscle group will be tested first will be counter-balanced from participant to participant.

All participants will have their sEMG recorded at their thumb (experiment one) or both triceps and thumb (experiment two) every trial by placing two electrodes (1 inch stickers that will allow us to record surface EMG) on the skin over those muscles. The task for all participants will be the same; each participant will be required to press a response switch as quickly as possible when they see a green orb (the stimulus) on the monitor. Five seconds will separate trials and sixty seconds will separate blocks. All participants will use their dominant side to complete all trials. All participants will complete testing in 25-30 minutes with one visit to the laboratory.

Benefits

As a participant in this research study, there will be no direct benefit for you; however, information from this study may benefit other people now or in the future.

Risks

By taking part in this study, you may experience the following risks: Minimal local skin irritation due to the surface EMG electrodes is likely. Breach of confidentiality: The subject identification will be in the form of an arbitrary number set (i.e. 101) only. This list will be kept locked in a cabinet in the laboratory where only the PI and primary advisor of the PI will have access to. No information will be supplied or shared in presentation and/or publication of this study.

Alternatives

You may choose not to participate in the study.

Study Costs

Participation in this study will be of no cost to you.

Compensation

You will not be paid for taking part in this study.

Confidentiality

All information collected about you during the course of this study will be kept confidential to the extent permitted by law. You will be identified in the research records by a code name or number. Information that identifies you personally will not be released without your written permission. However, the study sponsor, the Institutional Review Board (IRB) at Wayne State University, or federal agencies with appropriate regulatory oversight [e.g., Food and Drug Administration (FDA), Office for Human Research Protections (OHRP), Office of Civil Rights (OCR), etc.) may review your records.

Your privacy is important to us. You will only be identified in the research records by a code number. When the results of this research are published or discussed in conferences, no information will be included that would reveal your identity.

Voluntary Participation/Withdrawal

Taking part in this study is voluntary. You have the right to choose not to take part in this study. You are free to withdraw from participation in this study at any time. Your decisions will not change any present or future relationship with Wayne State University or its affiliates, or other services you are entitled to receive.

The PI may stop your participation in this study without your consent. The PI will make the decision and let you know if it is not possible for you to continue. The decision that is made is to protect your health and safety, or because you did not follow the instructions to take part in the study

Questions

If you have any questions about this study now or in the future, you may contact Ron Benedict or one of his research team members at the following phone number (313) 577-4246. If you have questions or concerns about your rights as a research participant, the Chair of the Institutional Review Board can be contacted at (313) 577-1628. If you are unable to contact the research staff, or if you want to talk to someone other than the research staff, you may also call the Wayne State Research Subject Advocate at (313) 577-1628 to discuss problems, obtain information, or offer input.

Consent to Participate in a Research Study

To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read, or had read to you, this entire consent form, including the risks and benefits, and have had all of your questions answered. You will be given a copy of this consent form.

Signature of participant	Date
Printed name of participant	Time
Signature of witness**	Date
Printed of witness**	Time
Signature of person obtaining consent	Date
Printed name of person obtaining consent	Time

**Use when participant has had this consent form read to them (i.e., illiterate, legally blind, translated into foreign language).

APPROVAL PERIOD

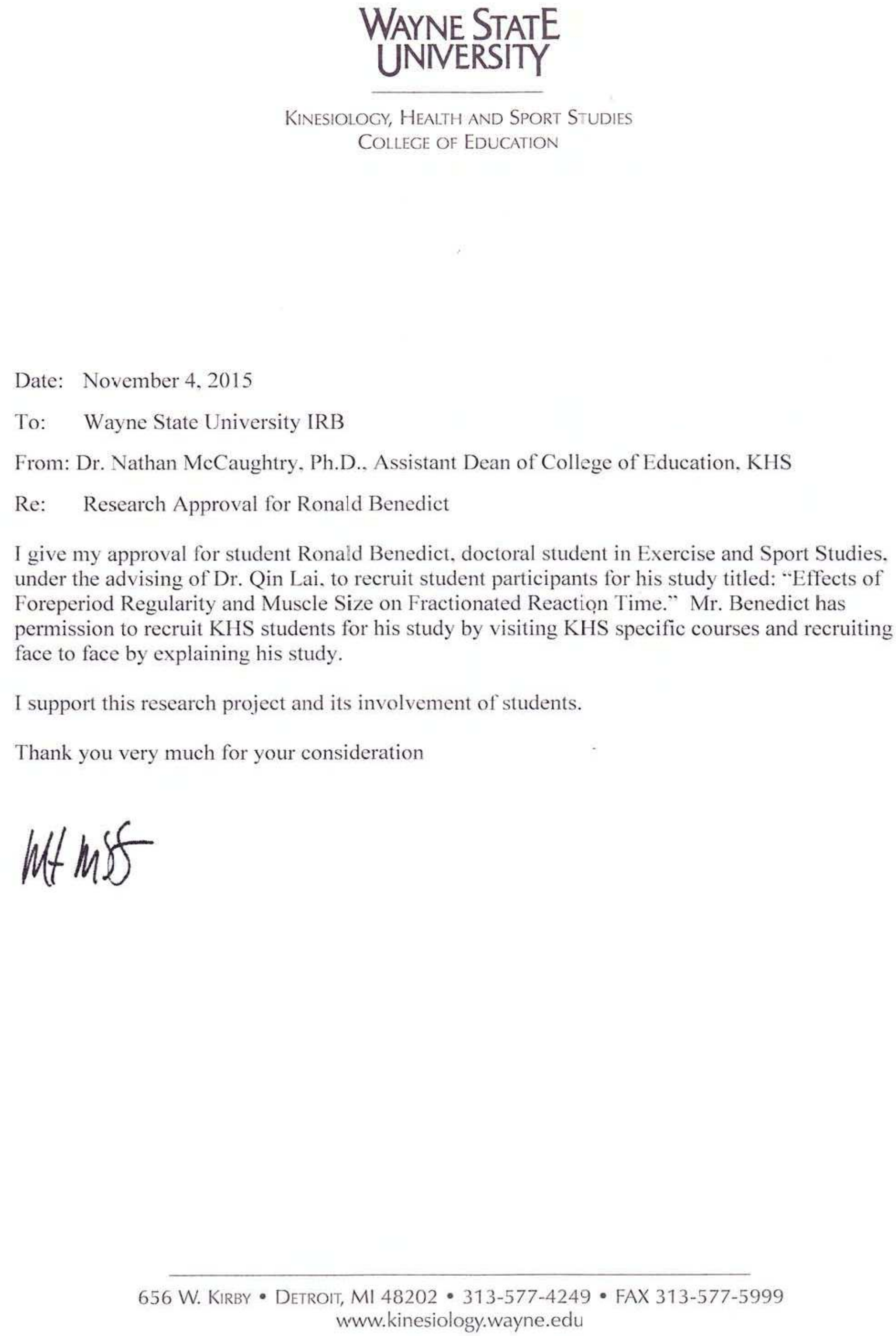
DEC 0 9 '15 DEC 0 8 '16

WAYNE STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Recruitment Script:

Students of Wayne State University in the age range of 19-30 who are physically healthy are the targeted population for participation in this study. The PI will contact potential participants in person. Students from KHS classes will be contacted after their class has ended and the faculty member has left the room. "Good Morning, my name is Ronny Benedict and I am a doctoral candidate in the Kinesiology, Health and Sport Studies Department. I am requesting your consideration to participate in my research. The study will have a dual purpose: the first is to determine whether manipulation of the timing interval preceding a visual stimulus has an effect on fractionated reaction time, the second is to determine if muscle size has an effect fractionated reaction time. If you choose to voluntarily participate in this study, you will be randomly assigned to an experimental condition, where your task will simply be to depress a response switch as quickly as possible when you see a green orb appear on a monitor in front of you, completing 6 blocks of 12 trails. Before the reaction time trials begin, I will place electrodes on your skin over your thumb flexor (flexor pollicis brevis), or elbow extensor (lateral triceps), or both, to measure the electrical activity in those muscles (sEMG). Testing will require 25-30 minutes and will be completed in one visit. The data I will be collecting from all participants will be your reaction time to a visual stimulus presented on a monitor, along with the sEMG of the thumb or triceps or both, which will be recorded automatically by the software program. If you are interested in participating or have any questions about my research, please contact me at AP0784@wayne.edu or 734-626-5921. Thank you for your time.

The potential participants who demonstrate interest will be invited to the Motor Behavior Laboratory where they will be presented with greater detail involving the equipment that will be used in the research and they will be provided an Informed Consent Form. Only those students, who sign the Informed Consent Form, will be invited to participate in the study.



WAYNE STATE
UNIVERSITY

KINESIOLOGY, HEALTH AND SPORT STUDIES
COLLEGE OF EDUCATION

Date: November 4, 2015

To: Wayne State University IRB

From: Dr. Nathan McCaughtry, Ph.D., Assistant Dean of College of Education, KHS

Re: Research Approval for Ronald Benedict

I give my approval for student Ronald Benedict, doctoral student in Exercise and Sport Studies, under the advising of Dr. Qin Lai, to recruit student participants for his study titled: "Effects of Foreperiod Regularity and Muscle Size on Fractionated Reaction Time." Mr. Benedict has permission to recruit KHS students for his study by visiting KHS specific courses and recruiting face to face by explaining his study.

I support this research project and its involvement of students.

Thank you very much for your consideration

656 W. KIRBY • DETROIT, MI 48202 • 313-577-4249 • FAX 313-577-5999
www.kinesiology.wayne.edu

Instructions for fractionating reaction time in Excel

Create a theoretical timed sequence of events '**RT guide**' for each block condition to expedite processing of the data.

In column A, each cell equals 1ms of EMG data recorded in mV.

In column B, the string of 5's represent the red orb on the screen, the first "0" in column B is the beginning of the foreperiod (yellow orb).

Use the '**RT guide' tab** as a guide to help you quickly sift through the "5's" and "0's" in column B.

For example, in a regular foreperiod trial (Foreperiod = 2,500ms), locate the first "0" in column B after the long string of "5's".

For example, 1ms to 1,000ms shows all 5's in column B. 1,001ms would show the first 0 in column B, which marks the beginning (the 1st ms) of the foreperiod.

Being that this is a regular foreperiod, you would add 2,500 to 1,000 = 3,500ms, which is the end of the foreperiod.

The next ms would be the stimulus onset (appearance of green orb), so 3,501ms would be the beginning of the reaction time.

If the **RT for that trial is 200ms (data points 3,701-3,501),** you will need to examine those 200 data points in column A for the beginning of a consistent increase (a significant pattern change in the EMG record) in the absolute value (disregard the + or – sign for mV) and log the time of the first value of the increase above baseline as the motor time (MT).

MT typically has a range from 30-80ms.

Continuing with the example above, if the **initiation of MT was observed at 3,651**, you then subtract the end of the RT from the observed MT.

3,701 – 3,651 = 50ms, which is your MT.

Then subtract RT from MT to find premotor time (PMT).

PMT = (200-50) = 150ms.

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ABSTRACT

EFFECTS OF FOREPERIOD REGULARITY AND MUSCLE SIZE ON FRACTIONATED REATION TIME

by

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Fractionating reaction time (FRT) chronometrically separates central (PMT) from peripheral (MT) processing, allowing for analysis of the variables that may have a timing effect on either. The purpose of this study was to determine the effect of foreperiod regularity and muscle size on the components of FRT. Forty-four male ($n = 21$) and female ($n = 23$) healthy Wayne State University students responded to a visual stimulus in a simple reaction time task, either by alternating foreperiod by block (Exp1) or by alternating muscle size by block (Exp2). All participants completed six blocks of eight trials using their right-side, with five seconds separating trials and sixty seconds separating blocks. FRT and surface electromyography (sEMG) data were collected digitally through the E-Prime 2.0 software and a BIOPAC MP100 System, which were fully integrated and time synced. Employing a counter-balance of condition, participants responded with a rapid thumb press for all trials with the foreperiod alternating by block (Exp1) or alternating between thumb press and elbow extension by block with all trials maintaining a regular foreperiod. Bipolar sEMG signals were recorded from the small abductor pollicis brevis (both experiments) and the large lateral triceps brachii (Exp2). In Exp1, significantly shorter times were observed during the regular foreperiod for mRT and mPMT. A significant interaction existed

between foreperiod grouping and sequence of foreperiod administration for mRT and mPMT. Specifically, beginning testing with a regular foreperiod produced the shortest mRT and mPMT, and beginning testing with an irregular foreperiod produced the longest mRT and mPMT. A sex difference between foreperiod groups was not significant for mRT, however, females demonstrated a significantly shorter mPMT in both foreperiod groups. MT was not significantly different for all analysis. In Exp2, significantly shorter times were observed with the small muscle for mRT, mPMT, and mMT. Also, the relative-timing analysis demonstrated a discrepancy between muscle sizes, supporting effector-dependence. No significant interaction existed between muscle size grouping and sequence of muscle size utilization. A sex difference was observed for both muscle size groups, with males demonstrating a significantly shorter mRT and mPMT, with no significant difference in mMT. Collectively, these findings highlight the effects of foreperiod regularity, influence of condition order, muscle size, and sex differences in simple reaction time. Future recommendations are made with potential implications for athletic training, coaching, and rehabilitation.

AUTOBIOGRAPHICAL STATEMENT

I was raised in Garden City, Michigan, where I lived with my older sister and mother until graduating from high school. I began taking classes at Henry Ford Community College (HFCC) in the Fall of 1999, which would ultimately play a serious role in my future. I was fortunate to have met a handful of passionate professors, whom, looking back, seemed to focus the majority of their time on the art of thinking, regardless of the course. Consequently, I was inspired to do more with my life, though at the time, I still wasn't sure what that would entail.

After a few semesters at HFCC, I began attending Eastern Michigan University with hopes of finding direction for the future and being the first to earn a bachelor's degree in my family. I took several different types of classes and ultimately became more confused with how I was going to transform a college degree into a meaningful life for myself. My mother suggested I enroll at Wayne State University (WSU), as she enjoyed her short time there before leaving to work fulltime. I took her advice and met with an advisor to discuss course selection, and based on our short meeting, she recommended I take a couple classes in Kinesiology, so I did. In a very short period of time, it became clear that I was finally on the right track.

I earned a B.S. in Education, majoring in Kinesiology in May, 2007. I accepted a graduate research assistantship at WSU beginning August, 2007, where my primary duties were to conduct research in the Motor Behavior Lab under Dr. Lai, and teach the Exercise Physiology Lab component under Dr. Engels. During my time as a graduate research assistant, I gained invaluable experience by working closely with Drs. Lai and Engels. Through the multiple experiments Dr. Lai and I conducted, I was able to travel and present our research all over the nation, from San Diego, CA, to Burlington, VT, and several places in-between, which was an amazing experience. However, the most important day in my adult life was January 11th, 2008, which was when I taught my first lab for Exercise Physiology. It was the most exhilarating time I ever had in any work environment and it was then that I knew my true calling in life. I graduated with a M. Ed, majoring in Kinesiology, and began work on the Ph.D. at WSU in August, 2010.

In August, 2013, I began a tenure-track position at New Mexico Highlands University as an Assistant Professor and Coordinator of Pre-Professional Allied Health Studies. There I taught and advised both undergraduate and graduate students in the Exercise and Sport Science Department for two years before resigning and returning to Michigan to complete my Ph.D. training. Upon completion of the Ph.D. degree requirements, I hope to obtain another full-time faculty position where I will create a passionate, thought-provoking environment, and continue to pay-forward the guidance and support freely given to me.