Effects Of Attention Focus And Warm-Up On Performance Of Central And Peripheral Processing

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EFFECTS OF ATTENTION FOCUS AND WARM-UP ON PERFORMANCE OF CENTRAL AND PERIPHERAL PROCESSING

by

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DISSERTATION

Submitted to the Graduate School

of Wayne State University,

Detroit, Michigan

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

2020

MAJOR: EXERCISE AND SPORT SCIENCE

Approved By

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Advisor Date

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DEDICATION

I dedicate my success to my family, professors, and friends.

To my mother who has always believed in me and gave me the confidence required to push forward. And to my wife and kids, for their unconditional love and encouragement.
ACKNOWLEDGEMENTS

I am grateful for all the support I received while working on my research. I am grateful to Dr. Qin Lai for his unconditional support of my research. I cannot imagine completing my study without his support. With his expert knowledge and wisdom, I was able to accomplish things that I never thought were possible. I would like to sincerely thank the committee members for their time and contributions to help me finish my dissertation with success. The professors, Dr. Ke Zhan, Dr. Moh H. Malek, Dr. Frank Castronova, and Dr. Qin Lai who were always readily available to answer questions, guide, and meet with me to ensure my success in my journey. I would like to acknowledge my family and all the people that participated in my research. Without all of you, this would have been impossible. Last but not least, my friends, who were there for me to reduce stress, talk out issues I was struggling with, and supporting me any way they could. Thank you all from the bottom of your heart for your patience, advice, guidance, and continuous support. Thanks to all of you I am where I am today. I say this with the deepest respect and love from the depths of my heart, thank you all!
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Chapter 1. Introduction

The study of motor behavior and control assumes that humans are capable of processing information (Schmidt & Lee, 2011). Information comes from sensory inputs, is stored, and then processed for many different functions, including motion (Anson, 1989). This conclusion has led to an interest in what influences the efficiency of information processing and how it relates to motor control. A model for information flow that leads to responses in living organisms can be illustrated as originating from the stimulus to receptor, integrator, and finally to an effector, which elicits a response. This model has been expanded in vertebrates to stimulus, sensory neuron, spinal cord or brain, and ultimately motor neuron, which produces the desired response.

Human functioning can be described in terms of the processing of information. The literature on cognitive psychology indicates that information processing occurs in three stages, which can further be grouped into serial (successive) or parallel (concurrent). The environment holds a lot of information that is accepted by an individual and kept in storage systems known as memory. The first stage involves the input of signals. During this stage, sense organs perceive information from the surroundings in a way similar to that of a computer receiving data. The information in the surroundings is considered a stimulus. The second step involves the processing of information within the individual, who is considered a black box in the black box model. A black box model considers the subject to be the box. Activities that occur in the box lead to the generation of outputs in the form of motor activity. Information processing could either be sequential or parallel. In sequential processing, one process must be completed before moving on to the next, whereas in parallel processing several inputs can be processed at the same time. These courses are usually carried out in the brain (Schmidt & Lee, 2011). The processed information then leads to the third stage, which is the production of a response or output.
The constituents of the black-box model of information processing can be compared to a physiological feedback loop where information flows from the stimulus (signal) to a receptor that perceives it. The integrator processes the signal and conveys the resultant feedback to the effector, which generates the desired response. In vertebrates, this model can be expanded to stimulus, sensory neuron, spinal cord or brain, and motor neurons that produce the anticipated response. This model can be used to describe how a human being processes an auditory stimulus to elicit a motor response. An example of this is athletes taking part in a sprint event. These athletes depend on a start signal, which is an auditory input from the environment. The signal is detected by the sensory system and then processed in the brain by being decoded to mean it is time to begin sprinting. The processed signal then moves from the brain to the muscles via the spinal cord resulting in the coordination of various muscles of the body and their contraction, ultimately resulting in a sprint start as the motor response (Ille, Selin, Do, & Thon, 2013). This example underscores the significance of the brain and spinal cord in the production of responses. Thus, information can be put to better use by optimizing performance (Wulf, 2013).

The most common strategy to investigate information processing is to examine the duration of these processes. This approach is referred to as the chronometric method, which takes advantage of reaction times to investigate the effect of various experimental factors. Information processing has been studied extensively through reaction time. A classical experiment involving reaction time was conducted in 1969, where the time for a subject to finish a simple motor task was measured and separated into the time needed to execute different operations in the task using a subtractive approach. This experimental procedure is the basis of the contemporary analysis of information processing (Donders, 1969; Yang, Bender, & Raz, 2015).
Although various models have been used to examine information processing, these models have three components in common (Figure 1): identification of the stimulus, selection of response, and response programming (Davranche, Burle, Audiffren, & Hasbroucq, 2005). The identification of the stimulus takes place as soon as the stimulus is produced. This phase can further be divided into two specific stages of stimulus detection and pattern recognition. Stimulus detection entails the preliminary triggering of nerves where the stimulus is situated and conveying the resultant electrical signal to the central nervous system (CNS). On the other hand, pattern recognition encompasses a blend of deliberate and intuitive processing in the CNS, which causes a stimulation of the pertinent associative memory (Schmidt & Lee, 2011). The strength of the stimulus, as well as the uniqueness of the task, have a substantial impact on the time taken during this processing stage.

![Figure 1. Three stages of information processing model](image)

The CNS receives and evaluates the signal, thereby leading to the second stage. In the response selection stage, the subject decides the most appropriate response to a given stimulus. The time taken to arrive at a specific response is determined by various aspects such as the sum of potential reactions to the stimulus, which is referred to as the stimulus-response (S-R) pairings. A predictable association exists between reaction time and S-R pairings, which has led to the development of Hick’s Law (Logan, Ulrich, & Lindsey, 2016). Hick’s Law states that reaction time increases by 150 ms for every twofold increase in S-R pairs (Kendall, 2018). The response
selection time is also affected by the congruence of the stimulus and response, which is the spontaneity of the response to a stimulus. Mixing the stimuli and responses can increase the reaction time, leading to the Simon Effect (Theeuwes, Liefooghe, & De Houwer, 2014).

The last stage of information processing is response programming. This step happens following the sensing and recognition of sensory inputs and the selection of the right response. It involves the execution of pertinent motor actions to attain the anticipated outcome. Reaction time as a measure of response programming under various conditions provides an indirect way to measure the processing steps that control the coordination of motor behavior.

The time needed for the response programming phase is influenced by many factors. Significant evidence indicates that the duration of the movement and the time of the movement play an important role (Klapp, 1975; Klapp & Erwin, 1976; Klapp & Wyatt, 1976; Ivry, 1986; Zelaznik, Shapiro, & Carter, 1982; Zelaznik & Hahn, 1985; Baba & Marteniuk, 1983). The role of movement direction, the number of moving parts, the side of the body used for movement, and the extent of the movement have also been extensively studied (Fischman, 1984; Larish & Frekany, 1985; Rosenbaum, 1980; Ivry, 1986; Baba & Marteniuk, 1983; Glencross, 1972; Lagasse & Hayes, 1973; Henry & Rogers, 1960; Zelaznik, Shapiro, & Carter, 1982; Jeannerod, 1984; Light & Spirduso, 1990; Annett & Annett, 1979; Nakamura, Taniguchi, & Oshima, 1976). Reaction time has also been shown to rise with an increase in the intricacy of movements (Anson, 1982; Christina & Rose, 1985; Kendall, 2018). However, precise attributes of movement complexity are reported to affect the reaction time. They include the sum of moving parts, the need for movement precision, and the interval of the movement. Movement complexity calls for the synchronization of more neuromotor actions, which subsequently elongates the time needed for neurologic arrangement thus leading to longer reaction times (Christina & Rose, 1985).
Reaction time can be defined as the time taken between the presentation of a stimulus and the production of a motor response related to the impetus (Dean & Baker, 2016). The actual effect of reaction time is realized by the decomposition of reaction time into its pre-motor and motor components using Electromyography (EMG) on specific muscles. These components match delays in the central nervous system that occur before the initiation of muscle action potential (MAP) as well as the muscular delays that take place from the first MAPs to the start of the movement (Suminski, Mardoum, Lillicrap, & Hatsopoulos, 2015). This fractionation makes it possible to ascertain the locus of temporal changes caused by experimental conditions, which would not be possible when considering reaction time as a whole (Christina & Rose, 1985).

Based on the information processing stages discussed above, it is impossible to obtain the precise processing time for each of the listed stages. Reaction time is frequently utilized to assess the duration of whole information process. However, it is possible to separate the neuromotor process from the central to peripheral parts as the previous research to componentize reaction time as pre-motor time and motor time. Namely, pre-motor time corresponds to the central processing of information while motor time corresponds to the peripheral processing. The precise steps involved in information processing are encoding of the input, activation of memory, making a decision, choosing a response selection, implementing the response. These steps are grouped into the central processing, while the peripheral processing refers to the action impulse initiation on the muscle up to actual start of a movement.

Experimental procedures that involve the active manipulation of the peripheral neuromuscular system or the central nervous system can be employed to measure the two components of reaction time (Kendall, 2018). The electromyography (EMG) of specific muscles is the most common technique used in this regard. In simple reaction time, a single response is
elicited from one stimulus, whereas in complex reaction time, the number of stimuli presented can cause different reactions. In such experiments, pre-motor time (PMT) encompasses the time between the presentation of the signal and a change in electrical signals in the muscle (measured through the EMG). The pre-motor variable is utilized in numerous studies where investigators are interested in stimulus processing, decision-making, or movement programming since it allows us to better understand how mental or central processes lead to movement (Schmidt & Lee, 2011). Conversely, motor time (MT) is the duration that elapses between the change in muscle signal and the start of limb movement (Davranche, Burle, Audiffren, & Hasbroucq, 2005). Conversely, the motor constituent of reaction time is the interval between the primary change in EMG and muscular movement. This time stands for all activities linked with the musculature (Schmidt & Lee, 2011). The sum of these two components provides the overall reaction time. This way, reaction time can be related to the different stages of information processing.

**Attentional Focus**

Attention is the dynamic that governs which mental depictions of information are processed to form memories and the speed with which it is processed. Attentional focus acts as a driving force on the information processing system (Williams et al., 2015). Research on attention and performance began in the 1950s with the development of attention theories such as the Single Channel theory, Filter theory, Attenuation theory, and Late Selection theory. The Multichannel Theory was introduced in 1971, after which the bottleneck of selection theory was later advanced in 1973.

Attention is believed to be established through local changes in neural gain (Eldar, Cohen, & Niv, 2013). Large-scale fluxes in neural gain regulate the magnitude of attention as well as the extent to which processing focuses on environmental attributes that an individual is exposed to.
The emotional content of audiovisual narratives is known to alter attention. For example, an increase in suspense lowers the activity of the peripheral visual processing regions, which increases the activity of central visual processing regions as well as the frontal and parietal regions enlisted for attention (Bezdek et al., 2015).

Attentional focus is related to many practical applications. In many sports including track and field sprints, the efficiency of the start often determines the final performance. An athlete is required to respond promptly to the ‘go’ sign, synchronize the movements of arms and legs, and engender adequate forces to exit the starting block and attain the maximum speed within the shortest time (Schmidt & Lee, 2011). Therefore, knowledge of the optimal conditions required to reach this goal is of utmost importance. Some studies focusing on the relationships between the processing of stimuli, deciding, and initiating movement have explored activities such as short races, particularly the starting point. It is reported that the outcome of a race and the time taken to complete it are largely determined by the start. Kovacs, Miles, and Baweja (2018) indicate that the start contributes to about 5% of the total time in a 100-meter race. Consequently, participants in such races need to take the least time possible to accelerate from the starting block after hearing the start signal (gunshot). This way, the athletes can attain the maximum velocity within the shortest time. For this reason, incorporating any measures that reduce race time could be advantageous to the participants (Kovacs et al., 2018). Such measures include enhancing the processing of information and the execution of movement. This observation is reiterated by Ille, Selin, Do, and Thon (2013).

A person’s focus of attention plays a vital role in the execution of motor skills (Wulf, 2007). The accuracy and quality of movements are determined by what the performer focuses on while executing motor skills. This observation has been corroborated by several studies (Pascua, Wulf,
& Lewthwaite, 2015; van der Fels, Te Wierike, Hartman, Elferink-Gemser, Smith, & Visscher, 2015). These studies show that while implementing a skill, a performer focuses on factors that affect his performance as well as the entire learning process. As a result, the speed of learning a new activity as well as the efficiency of performing and retaining the skill is influenced by the subject’s focus of attention that is induced by instructions or feedback provided.

Two important loci of focus exist: internal and external. Internal focus aims attention at the body or the specific muscle of the subject while external focus aims attention at the external stimulus that will trigger the performer’s movements. Studies show that attentional focus influences the efficacy of different types of movement, including balance tasks, precision, and motion efficiency (Wulf, 2007; Wulf, 2013). These effects occur as a result of muscular activity that releases maximum force, speed, or endurance (Wulf, 2013). Many studies have been conducted using different theories to evaluate how attentional focus influences the performance of different motor skills since the 1990s (Williams et al., 2015). The theoretical hypothesis was the constrained action hypothesis, which proposed that directing attention to external focus (also referred to as movement upshot) paved the way for an involuntary mode of movement regulation, leading to the attainment of the anticipated upshot as a spinoff. Conversely, when people attempt to micromanage their movements consciously (internal focus), evidence indicates there is a higher likelihood of constraining the motor system by meddling with the process that would otherwise control the synchronization of their movements (Wulf, 2007).

Studies have been conducted to contrast the efficacy of the two forms of attentional foci using different motor skills such as jumping, throwing, balance, golf, and basketball (Wulf, 2007; Oki et al., 2018). Much of the literature indicates that the external focus of attention yields better outcomes for motor performance and learning than the internal focus (Wulf, 2007; Wulf, 2013;
The benefits of external focus apply to a wide range of skills and levels, which have been established in young adults, children, in addition to individuals with physical insufficiencies. These factors are also known to determine reaction time, which is the time required for an individual to respond to a stimulus or event. Conversely, other studies have tweaked the subjects’ attentional focus through instructions and feedback (Brown & Ferrigno, 2014); at least one study found differential effects based on attentional focus, across both motor movement and forcefulness (Oki et al., 2018). Tsetseli, Zetou, Vernadakis, and Michalopoulou (2016) examined the effects of internal and external focus of attention on various participants of game performance in tennis. These included skill implementation, base, and decision making, which were measured using the Game Performance Assessment Instrument (GPAI) in three game conditions. There was a significant improvement in the decision-making skills of the group that received instructions to focus externally. A similar trend was noted for the retention test and it was concluded that decision making could benefit from instructions that target the external focus of control.

Another aspect of peak performance that improved with an external focus of attention was jumping height in physical activity. Wulf, Dufek, Lozano, and Pettigrew (2010) investigated the nervous system activity using EMG and observed that greater jump heights and lower EMG activities were obtained with an external focus of attention compared to the internal focus, further verifying the results of previous studies. Similarly, Hill, Schücker, Hagemann, and Strauß (2017) demonstrated that the external focus resulted in a better movement economy in endurance sports. Cohn (1991) showed that mental relaxation, similar to an external focus, enhanced peak performance. Brewer, Van Raalte, Linder, and Van Raalte (1991) also reported that an external focus of attention together with positive feedback enhanced peak performance in competitive
sports. Many studies from different time periods, using different methods of experimentation, have consistently shown that an external focus leads to greater peak performance.

Ille et al. (2013) hypothesized that the progressive impact of the external focus of attention would be noted in the three stages of a race start in skilled and inexperienced athletes. The external focus led to a time saving of 0.09 seconds out of which 0.06 seconds were attributed to the running time and 0.03 seconds to the reaction time. The findings supported claims that an external focus at the pre-movement time influenced the learning of a force-generation task. Attentional focus affected the formulation of movement as well as its implementation. This effect could be explained by several factors that are known to shape reaction time. First, ambiguity concerning the response prolongs the reaction time because it advances the informational processing phase of the response-selection stage. As reported earlier, an increase in response processing prolongs the reaction time due to more sub-constituents that require formulation and instigation. It is presumed that this factor can be affected by attentional focus. The nodal-point hypothesis proposes that an internal focus of attention breaks up the sensorimotor chain in sub-portions, which results in the formulation of two sub-parts of the action as opposed to a whole functional element. This effect is more pronounced in the motor than the pre-motor reaction time (Christina & Rose, 1985). It was suggested that subjects tried to organize their movement consciously in an internal focus, whereas these movements occurred spontaneously in the external focus. Planned responses are more resource-intensive and slower than spontaneous ones, which explains the faster reaction times in the external focus. Finally, it was suggested that longer reaction times ensued when attention was aligned with the implementation of the response (motor set) in contrast with alignment with the sensory set (impetus). It was also suggested that urging the participant to concentrate on details of response implementation delays response formulation and extends the reaction time. Therefore, an internal
focus of control impels subjects to give more attention to the completion of the impending movements, thus attenuating their capacity to respond to the gesture.

In a separate study, Wulf (2013) conducted a 15-year review of attentional focus and motor learning. The outcomes showed that instruction or feedback that prompted the external focus of attention yielded better outcomes in terms of performance and learning in various tasks and skill levels across different age groups. These observations were explained by Prinz’s common coding theory of perception and action, which hypothesized that the brain has a common depiction of insight and action as distal occurrences. Consequently, it is possible to conduct commensurate coding and attain the observed outcomes. The review also examined studies of numerous activities, including balance tasks, golf, basketball, dart throwing, American football, and jumping. The common consensus was that the external focus of attention was more effective than the internal one. These effects are also evident in healthy adults and children as well as elderly populations with Parkinson’s disease. These observations are attributed to the fact that an external focus favors automaticity in movement control. Conversely, focusing on the movements themselves limits the motor system because the subject tries to wield conscious control over their movements.

Employing different focus influences electromyographic (EMG) amplitude and contraction duration (Calatayud et al., 2017). For example, Calatayud et al. (2017) report that a controlled speed state boosted pectoralis normalized EMG (nEMG) by 6% and the triceps muscles nEMG by 4% as opposed to a regular focus state. Using different focuses did not affect the nEMG during the explosive speed condition. Therefore, using an internal focus to augment EMG amplitude is only effective under a controlled speed.
Warm-Up

In addition to attentional focus, warm-up strategies may influence information processing and reaction time. Studies indicate that warm-up has an overall positive effect on people’s physical and psychological states (Frikha, Chaâri, Gharbi, & Souissi, 2016). Warm-ups improve blood circulation and increase the temperature of muscles, which is critical for enhancing performance and preventing injuries. Regarding the mental aspect, warm-ups lead to psychological stability and preparedness for, as well as overall confidence in, performance (Kendall, 2018). Recent studies have shown that cognitive performance is improved following light and light-moderate exercise compared to intense exercise (Lambourne & Tomporowski, 2010). Studies have shown that warm-up or acute exercise can improve reaction time, inhibitory control, memory, attention, and other aspects of executive function (Tomporowski, 2003; Roig et. al, 2013; Ludyga et al., 2016). Another study by McCrary, Ackermann, and Halaki (2015) have found that different types of warm-ups have diverse or even no effect, their results indicate that it is essential to choose the most effective exercise to prepare athletes for productive training and excellent performance. For example, some research has indicated that a medium exercise intensity can improve executive function and higher intensity exercise may improve information processing (Chang et. al, 2011). The link between warm-ups and central processing via cognitive function is well-established in the literature (Chang et al., 2012; Magill & Anderson, 2017). Kendall showed that short periods of exercise can improve motor functions and information processing through a significant reduction in pre-motor time via central processing (2018). In addition to central processing and cognitive function, some studies have examined the associations between warm-up or acute exercise and peripheral processing and motor functions. There is evidence that acute exercise can reduce motor time through muscle activation, thereby influencing peripheral processing.
(Audiffren et al., 2008; Sanders, 1983). However, the potential role of warm-up on peripheral processing remains unclear and warrants further research.

Warm-up and attentional focus have also both been linked to fatigue. It has been found that warm-ups can have a twofold impact on performance and fatigue (Salgado, Ribeiro, & Oliveira, 2015). On the one hand, these activities may lead to fatigue, especially when conducted improperly. Silva and colleagues (2018) noted that intensive warm-ups combined with a short period of rest lead to better performance and delayed fatigue, which is specifically apparent in team sports. Increased attention has been associated with a higher degree of fatigue, especially when it comes to some types of focus. For instance, a low level of focus on the relevant aspects of tasks has been associated with higher performance and delayed or less intensive fatigue. The focus on irrelevant components of the task leads to increased fatigue and lower performance (Bertollo et al., 2015). It is pivotal to make sure that athletes carry out warm-ups properly (with definite intensity and intervals) to enhance performance and learning while decreasing and delaying fatigue. Attention focus is another important aspect to consider as athletes’ performance may decrease due to increased fatigue. The literature suggests that there is a link between attention focus, warm-up, and performance, and this study aimed to investigate this relationship further.

**Scope and Significance of this Study**

The main purpose of the present study is to investigate the impact of attentional focus and warm-up on the central processing and the peripheral processing, indexed by pre-motor and motor components of reaction time, respectively. Previous research showed the external focus of attention decreased reaction time by increasing central processing speed, compared to the internal focus of attention. The research suggests that there is a direct link between attentional focus and information processing. It is also well-documented that warm-up or moderate exercise increases
the central or cognitive processing speed even though no consistent finding on the latency of the muscle activation. However, there is little research on the potential role of warm-up on central or peripheral processing linked with attentional focus. The proposed experiments will empower an innovative data collection system to assess the effects of warm-up and attentional focus on human information processing in different research designs (between groups and within groups) and different limb actions (the upper extremity and lower extremity).

This proposed research would increase our understanding of how physical activity (i.e., warm-up) interacts with important cognitive activity such as attentional focus for human information process and motor control. Beyond theoretical significance, this research would have practical importance in sports and other fields related to human motor performance. For example, the findings from this study would practically benefit professionals such as sports physiologists and occupational therapists to integrate moderate physical activity with cognitive manipulation for enhancement of human motor performance and rehabilitation.

**Research Questions and Hypotheses**

This research aimed to answer the following broad research questions through two separate experiments.

1. Does attentional focus affect information processing, including central and peripheral components?

2. Does attentional focus affect information processing independent of research design (i.e., between groups vs. within-group) and effectors (i.e., the upper extremity vs. the lower extremity)?

3. Does warm-up affect attentional focus effects on information processing, including central and peripheral components?
The following hypotheses are associated with the above research questions:

- **H1**: External focus of attention would lead to significantly faster reaction time compared to internal focus of attention.
- **H2**: External focus of attention would lead to a significant reduction of the central processing time (pre-motor time) but not peripheral activation latency (motor time), compared to internal focus of attention.
- **H3**: Attentional Focus effects would be independent of different research designs and muscle effectors.
- **H4**: Warm-up exercise would lead to significantly increased information processing speed, including central peripheral processing and peripheral activation, compared to the no warm-up control.
- **H5**: External focus and warm-up would lead to significantly increased information processing speed including both central and peripheral components when compared to no warm-up with internal focus.

**Assumptions**

There are several assumptions associated with the proposed experiments. First, we assume that participants understand and follow the task instructions; that is, they truly focus on the task-at-hand and perform as quickly as possible. Second, we assume that participants are truthful in their responses about their physical health, including informing the investigator about any physical health issues that may affect their performance. This also entails assuming that participants are not under the influence of any substances (e.g. medications, alcohol, or drugs) which may impair performance and that they are not overly tired. There are also assumptions about the computer software: that it can track transmission delays for foreperiod and stimulus onset as well as reaction
time and that the integrated software maintains a one-to-one timing ratio during the acquisition of the data gathered.

**Limitations**

There are some important limitations to note. First, participants may have previous reaction time training from engaging in sports, video games, or brain training. Participants may also have some distractions such as illness (cold/flu, headaches, or watery eyes). Another limitation is that the monitor is set to refresh at a rate of 80 hz. However, we have taken steps to limit the impact of these limitations on the results.
Chapter 2. Literature Review

Motor skill acquisition is a complex process that has been researched for decades. Diverse aspects of this type of learning have been researched in detail including the exact mechanisms utilized to perform tasks, processes that take place in the brain, memory, data processing, to name a few. The research on these processes and concepts started as far back as in the nineteenth century, but there are still various gaps (Benedict, 2016). It has been acknowledged that memory and anticipation are two important components leading to improvements in people’s performance as individuals choose the most appropriate patterns to perform a task (Afonso, Garganta, & Mesquita, 2012). Motor skill learning is also closely related to the concept of action control that consists of two phases (Elsner & Hommel, 2001). First, the action is conducted based on a set of external factors and internal capabilities. During the second stage, the obtained knowledge is utilized to produced the required activities. This literature review highlights some theoretical frameworks related to the concepts in question, as well as the most recent findings associated with information processing and motor time.

Closed-Loop Theory

According to motor learning theories, attentional, as well as cognitive, demands of the execution of a task decrease if practice increases (Ille, Selin, Do, & Thon, 2013). A closed-loop theory developed by Jack Adams in the 1970s was one of the first motor learning theories that offered testable hypotheses that gave a considerable impetus to the research related to the acquisition of skills (Schmidt & Lee, 2011). This theoretical framework is associated with perceptual and cognitive constructs that initiate and tune movement separately and operate in a closed-loop system (Benedict, 2016). Perception is involved in the assessment of errors in motor
learning tasks and is the first construct. Feedback is seen as the key element in the process of a person’s movement modification.

Figure 2. Closed-loop Control Model

Based on this theory, such neural components as a perceptual and memory traces are central to the process of motor learning. The former is seen as the reference instrument employed to assess errors when learning skills (Benedict, 2016). During every trial, the perceptual trace is a record of a movement performed several times. The learner utilizes knowledge of results to improve performance during every trial, and each record strengthens the existing memory regarding the expected response (Schmidt & Lee, 2011). If necessary, certain adjustments to movement are made based on the gained knowledge of results, so perceptual trace also serves as a reference for correctness. When the necessary number of trials is implemented, the perceptual trace is created. Combined with knowledge of results and feedback, the perceptual trial leads to the movement changes, so learning occurs.

The other construct involved in the process is the memory trace that identifies and initiates the most appropriate response. The memory trace does not depend on the perceptual trace and
feedback (Benedict, 2016). Therefore, the closed-loop theory is deeply rooted in the assumption that the process of detecting and correcting errors is central to the learning process. Benedict (2016) stated that this theoretical paradigm was highly applicable with simple graded movements but was less effective with other types of moves.

Schema Theory

The schema theory was one of the theoretical frameworks that addressed the limitations of the closed-loop theory. Approximately five years after the development of Adams’s theory, Schmidt introduced his theoretical model as a response to the closed-loop theory (Schmidt & Lee, 2011). The major criticism was related to the primary role of feedback and the lack of attention to response variability (Benedict, 2016). Schmidt argued that action sequences could be controlled centrally rather than facilitated by feedback. The researcher also stressed that the response could adapt flexibly to new circumstances (Benedict, 2016). Schmidt assumed that action effects were predicted, so the comparison of planned action with expected outcomes enabled this internal test to monitor movement execution (Harrison & Ziessler, 2016). According to schema theory, the anticipation of responses is also instrumental in detecting and correcting errors (Ziessler, Nattkemper, & Vogt, 2012). It is noteworthy that the two theories mentioned above bore some similarities.

For instance, Schmidt introduced the concepts of recognition schema and recall schema that were similar to Adams’s perceptual and memory traces (Benedict, 2016). According to the schema theory, the recall schema selects response movements based on previous trials to improve the existing pattern. This concept is similar to Adams’s memory traces that implied the focus on memory capability. The recognition schema assesses the correctness of the chosen movement and creates sensory consequences adding the new outcome to the current recognition mechanism. It is
necessary to note that these theoretical perspectives are instrumental in explaining the processes that take place during data processing and response. They address different facets of the matter, which enables researchers to view the processes from different angles.

**Effector Independence and Generalized Motor Program**

As mentioned above, the schema theory assumes that movements can be structured centrally and are not tied to feedback. The motor program concept is closely related to this assumption. The motor program can be defined as a “sequence of stored commands” established and selected before the implementation of an action that ensures the completion of the necessary sequence (Benedict, 2016, p. 17). Researchers described the exact areas of the brain where this process could take place (Anson, 1989). Schmidt and Lee (2011) noted that each movement needed a program, which led to serious issues related to memory and novelty.

![Figure 3. Elements of Open-Loop Control](image)

It seemed logical that longer and more complex sequences required more storage space, so it was unclear how this bulk of information could be stored (Anson, 1982). For instance, researchers estimated the required memory capacity for different processes. It was reported that
comparatively easy operations such as linguistic required 10,000 programs, which would need considerable brain capacity. At the same time, the novelty problem was also quite relevant because researchers could not explain the human ability to perform new tasks that were not associated with survival (Benedict, 2016). The explanation was provided in the 1970s although the experiments justifying such assumptions had been implemented as far back as the 1940s.

Schmidt assumed that generalized motor programs existed, which provided a solution to the novelty and storage problems (Benedict, 2016). One of the first experiments that provided the background for such hypotheses was the one conducted by Lashley in 1942 (Benedict, 2016). The
participants wrote certain extracts using both hands and mouth. It was found that the major features of handwriting (such as the length of lines) were preserved irrespective of the utilized part of the body. Therefore, it was suggested that sequences were effector independent and the movement was stored in memory rather than muscle. Effector independence refers to an individual’s capacity to implement sequences using different muscle groups (Benedict, 2016). The introduction of the concept of generalized motor programs facilitated further exploration of motor skill acquisition and other areas.

The existence of generalized motor programs leads to the decreased use of memory capacity and enables people to perform novel tasks that may seem unnecessary for functioning or survival. Generalized motor programs are also linked to decreased motor time and people’s ability to learn faster and more effectively. They learn new sequences based on existing knowledge and external factors. The understanding of the mechanisms related to generalized motor programs is critical for motor skill learning research.

**Hierarchical Organization of the Brain**

The complex structure of the brain ensures the simultaneous completion of diverse tasks as different areas of brain control specific functions. Movement control is closely linked to the hierarchical structure of the brain as people’s actions may be controlled at different levels. For instance, sensory information and motor data are controlled at the highest levels of the structure and are defined as association areas that provide “a way to associate sensory feedback to motor output” (Benedict, 2016, p. 21). For instance, the visual data received by the retina are sent to the
parvocellular layers in the thalamus and further transmitted to the occipital lobe, primary visual cortex, in particular.

Eventually, the data is sent to the frontal lobe where the necessary functions are selected. In this area, the information received from the retina is used to develop a program, which is linked to pre-motor and supplementary motor areas. The developed program is transferred to the primary motor cortex, and the corresponding movements are completed (Anson, 1989). The implementation of the action is also related to the analysis of external factors that takes place at higher layers of the brain. It has been found that although similar areas of the brain are involved in specific processes, humans have a different brain composition, which influences their learning capacity.

**Fractionated Reaction Time**

The literature on reaction time is extensive and covers a wide range of topics, including physical and mental exercise (León et al., 2015), diseases such as Parkinson’s disease (Kwon et al., 2014), occupational hazards (Mortazavi, 2013), and stimulants such as caffeine or alcohol (Martin & Garfield, 2006). The concept of reaction time being fractionated into central and
peripheral processes was introduced by Weiss (1965), who demonstrated it by examining the beginning of electrical activity in the agonist muscle. Pre-motor time (PMT), which represents central processing, has been defined as the time from the onset of the stimulus until muscle action potential. Motor time (MT), which represents peripheral processing, has been defined as the time from the muscle firing to the explicit movement. Figure 6 shows the pertinent events in FRT with the EMG record of the abductor pollicis brevis for one trial.

![Diagram of Fractionated Reaction Time](image)

Figure 6. Fractionated Reaction Time

Despite evidence for fractionated reaction time, few researchers have adopted the use of FRT techniques. The use of fractionated reaction time has helped collect data on where the effects of different independent variables are located, including in large-scale movements (Christina et al., 1982; Christina & Rose, 1985; Fischman, 1984). It has also been instrumental in studying inertial load (Anson, 1989) and accuracy demands (Fischman & Mucci, 1990; Sidaway, 1991). The foreperiod, representing the time between a warning signal and the initiation of the stimulus, has been investigated in terms of its influence on total reaction time (Karlin, 1959;
Drazin, 1961; Näätänen, 1972), but few studies examine its impact on fractionated reaction time (Botwinick & Thompson, 1966; Kawama, 1996).

**Electromechanical Delay and Motor Time**

Apart from brain structure and central processing time, peripheral mechanisms also attracted considerable attention as these aspects were instrumental in explaining reaction time differences. The central processing time is associated with data processing delays, encoding, and other events. The peripheral factors include such events as the initiation of the contractions of muscles, as well as anatomical units such as forearm or finger (Anson, 1982). Electromechanical delay is referred to as the “electromechanical and biochemical occurrences, in concert with the muscles’ morphological properties, which are responsible for the delay in muscular tension development” (Benedict, 2016, p. 24). This notion involves mechanical aspects and electrochemical processes. An illustration of the delay is the fact that a muscle with a larger mass requires a more significant net force to start an action of the corresponding body part.

Information processing, the identification of the most appropriate program, and the implementation of the movement require time. Researchers started paying increased attention to the motor time in the 1960s, but the investigation of this notion is still ongoing. It has been acknowledged that response time depends on the complexity of the required action (Christina & Rose, 1985; Kendall, 2018). Pre-motor time is the period between the start of the response stimuli and the start of the electromyographic activity (Davranche, Burle, Audiffren, & Hasbroucq, 2005). Motor time can be defined as the interval between the start of the electromyographic activity and the necessary motor response (Davranche et al., 2005). Benedict (2016) noted that motor time could depend on central processing peculiarities. Yang, Bender, and Raz (2015) note that age differences in brain composition have a certain impact on people’s response time and accuracy.
In this respect, the electromechanical delay is seen as the time interval between the start of the stimuli and the creation of the tension in the corresponding muscles. This process included four major elements responsible for the conduction of the movement (Benedict, 2016). The first component is the implementation of the “motor unit action potential along with the T-tubule system” (Benedict, 2016, p. 24). The following elements are calcium release and the creation of tension in the contractile component. Finally, the stretching of the series elastic element takes place. Benedict (2016) noted that researchers attempted to measure the electromechanical delay. According to these inquiries, the electromechanical delay could fluctuate between 25 and 85 milliseconds. Benedict (2016) added that only male participants took part in the research, which is a considerable limitation to be addressed in further studies.

External factors also have an impact on motor time, which was analyzed in several studies. For example, Theeuwes, Liefooghe, and De Houwer (2014) explored the effects of task-irrelevant aspects, such as stimuli position on response time. The participants made spatial responses to non-spatial stimuli. The researchers found that people performed better if spatial clues matched the response position. Anticipation and memory played an important role in the process, which needs to be further considered.

Many researchers investigated the possibility to reduce motor time through different practices, including motor skill learning. These inquiries led to the development of several laws such as Hick’s law (Logan, Ulrich, & Lindsey, 2016). According to this law, response time increases when stimuli reaction pairings increase. Logan et al. (2016) conducted a study that involved the analysis of typists’ skills. The researchers found that typists’ automaticity depended on their attention and response control type. These findings are relevant to the investigations associated with learning in diverse settings.
**Broadbent Filter Theory**

Broadbent filter theory was the first comprehensive theoretical framework regarding attention and associated processes. The model was based on the analysis of several studies on selective hearing implemented in the first part of the twentieth century. Broadbent (1958) developed the filter theory that stemmed from his interest in the communication of pilots and radar operators during the Second World War. Operators had to communicate with several pilots at a time and react to diverse situations. The major Broadbent’s contribution was the use of information processing concepts from computer science and mathematics to explain psychological phenomena (Driver, 2001). The researcher found central processing parameters of computers similar to the attentional parameters of humans’ information processing. Broadbent developed a clear and comprehensive flow-diagram describing his concepts, and the model became widely used in cognitive psychology and neuropsychology (Figure 7).

![Broadbent Filter Theory Diagram](image)

**Figure 7. Broadbent Filter Theory**

Broadbent (1958) suggested that two stages of perceptual processing were associated with selective shadowing. The first stage relates to the processing of physical features, such as pitch and voice location, and their removal from the incoming stimuli. The second stage is characterized by the subtraction of psychological components, such as word meaning. Second-stage processing
is safeguarded from the overload by the selective filter that lets certain physical features go through. Selective attention can be optimal when the involved physical traits of the parallel stimuli are clear.

Researchers tried to analyze people’s processing of unattended messages using diverse methods. For instance, people were asked surprise questions about non-shadowed messages after they processed shadowed data. The measurement was seen as ineffective as people could have forgotten some information rather than not paying attention to it (Driver, 2001). Such findings and assumptions encouraged researchers to explore the peculiarities of attention, which had been seen as a single channel of perception.

For example, Gary and Wedderburn (1960) utilized another method and provided syllables or short phrases to the participants’ ears simultaneously (Table 1). Although the middle of the message was presented to the unattended ear, the participants could recall it properly. In another study, the participants’ names were encoded in unattended messages, and only one-third of them noticed their names (Moray, 1959). The results of controversial studies also suggest that people can process unattended messages. One such study involved the use of electric shock (Corteen & Dunn, 1974). An electric device attached to the participants’ finger was on whenever they heard some words. When the participants heard the words in unattended messages, they reported that they felt electric shocks although the device was not working.
Table 1

*An Example of Phrases Breakdown and Words in Gray and Wedderburn (1980)*

<table>
<thead>
<tr>
<th>Syllable</th>
<th>Phrase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Ear</td>
<td>OB-2-TIVEE</td>
</tr>
<tr>
<td>Right Ear</td>
<td>6-JEC-9</td>
</tr>
<tr>
<td>Participants</td>
<td>OBJECTIVE</td>
</tr>
</tbody>
</table>

In the study implemented by Lewis (1970), it was found that message shadowing was influenced by the provision of data containing the words with similar concepts or meanings in non-shadowed messages. The interpretation of the shadowed message was affected by the non-shadowed data. Hence, a wealth of evidence regarding the filtering process was available, so a theory explaining unattended stimuli processing was needed. One of Broadbent’s students, Treisman (1960), applied a modified version of her teacher’s theory to explain unattended messages processing. Treisman (1960) suggested that data was subjected to the attenuation process rather than complete blockage or rejection during the filtering process. According to this framework, attended and unattended messages passed through the second stage, and the unattended stimuli were weaker than attended ones. Nevertheless, when the unattended messages are simple and have a sufficient amount of meaning, they are processed properly. The illustrations of this phenomenon are Moray’s (1959) study with participants’ names or the study by Corteen and Dunn (1974) that involved electric shock that made the stimuli receive an emotional component.

The background for the attenuation theory was set in 1960 with the study implemented by Treisman. The participants received two messages in each ear, and one of the messages was
shadowed. The researcher switched one of the keywords in each message, so one word did not fit. The participants were able to replicate the correct message although the necessary word that fitted the context was shadowed. Underwood (1977) used a similar method, but the participants received complete sentences in each ear, and it was concluded that the sentences were perceived as semantic frames only in attended messages.

**Different Types of Selection**

Treisman’s theory was questioned as there was no understanding of how decisions about exact components to be attenuated were made by the filtering system. It was unclear whether the stimuli were attenuated or whether they were filtered during another phase of the selection process. Deutsch and Deutsch (1963) addressed the question and suggested that people’s awareness of the unattended messages is limited due to its rejection from entering into memory or controlled responses. The researchers stated that the data was processed fully but remained out of individuals’ control due to this kind of rejection. In simple terms, people process both attended and unattended stimuli but do not form memories or cannot respond to the message. Norman (1969) stated that unattended messages reach short-term memory but do not get through to long-term memory.

The research regarding the process of filtering was expanded by Keele (1973), who suggested his own model. In terms of this framework, both attended and unattended messages are processed with no attention paid to the messages during the identification and response selection stages. At the early preparation phases, information or some of its components associated with the stimuli are prepared for sudden reactions or planned processing. These preparations start at later stages of the selection of the most appropriate responses.
Multi-Channel Hypothesis

As seen from the review of the research on attention implemented in the middle of the twentieth century, the single-channel theory was largely supported. Although various findings and interpretations pointed at certain peculiarities of the selection process, it was agreed that humans concentrated on one stimulus at a time. It was also believed that people could process attended and unattended stimuli, but they would not remember the latter ones.

However, Allport, Antonis, and Reynolds (1972) proved that attention was multi-channel. In the research, Allport et al. (1972) provided different types of stimuli to the participants. The fact that the researchers used visual and auditory messages was the major difference between their study and the ones implemented earlier. It was found that the participants could remember visual messages in detail although the processing system was shadowing auditory stimuli at that period. During another experiment, the participants were asked to play the piano and simultaneously shadow a message. These experiments show that people can process different stimuli, so the
single-channel theory could not be applied universally. Allport et al. (1972) stressed that the single-channel theory could be relevant in some cases. The brain operates in a single- or multiple-channel manner depending on the level of concentration and the tasks to be performed.

The issue of dual-tasking often arises while attempting to elucidate the specifics of information processing and movement. Dual-tasking denotes the execution of two activities concurrently. This paradigm helps distinguish the function of attention on motor regulation. It is hypothesized that the attention given to a single task is drawn from a pool of resources (Jehu, Desponts, Paquet, & Lajoie, 2015). The common observation is that an individual can only focus on a task for a specified duration, which implies that the capacity to process information is restricted. Consequently, when attempting to complete two tasks at the same time, the overall attention capacity is surpassed, leading to a dual-task interference upshot that may ultimately interfere with the performance of the two tasks that are contending for the same resources. Dual-task models can also be used to assess the effect of information processing requirements of execution with other minor tasks, including those involving reaction time (Jehu et al., 2015).

**Attentional Focus**

Attention is the dynamic that governs which mental depictions of information are processed to form memories and the speed with which it is processed. Attentional focus acts as a driving force on the information processing system (Williams et al., 2015). Research on attention and performance began in the 1950s with the development of attention theories such as the Single Channel (1952) theory, Filter (1958) theory, Attenuation (1958) theory, and Late Selection (1960) theory. The Multichannel Theory was introduced in 1971, after which the bottleneck of selection theory was later advanced in 1973.
Attention is believed to be established through local changes in neural gain (Eldar, Cohen, & Niv, 2013). Large-scale fluxes in neural gain regulate the magnitude of attention as well as the extent to which processing focuses on environmental attributes that an individual is exposed to. The emotional content of audiovisual narratives is known to alter attention. For example, an increase in suspense lowers the activity of the peripheral visual processing regions, which increases the activity of central visual processing regions as well as the frontal and parietal regions enlisted for attention (Bezdek et al., 2015).

Attentional focus as many practical applications. In many sports including track and field sprints, the efficiency of the start often determines the final performance. An athlete is required to respond promptly to the ‘go’ sign, synchronize the movements of arms and legs, and engender adequate forces to exit the starting block and attain the maximum speed within the shortest time (Schmidt & Lee, 2011). Therefore, knowledge of the optimal conditions required to reach this goal is of utmost importance. Some studies have focused on the relationships between the processing of stimuli, deciding, and initiating movement have explored activities such as short races, particularly the starting point. It is reported that the outcome of a race and the time taken to complete it are largely determined by the start. Kovacs, Miles, and Baweja (2018) indicate that the start contributes to about 5% of the total time in a 1000-meter race. Consequently, participants in such races need to take the least time possible to accelerate from the starting block after hearing the start signal (gunshot). This way, the athletes can attain the maximum velocity within the shortest time. For this reason, incorporating any measures that reduce race time could be advantageous to the participants (Kovacs et al., 2018). Such measures include enhancing the processing of information and the execution of movement. This observation is reiterated by Ille, Selin, Do, and Thon (2013).
A person’s focus of attention plays a vital role in the execution of motor skills (Wulf, 2007). The accuracy and quality of movements are determined by what the performer focuses on while executing motor skills. This observation has been corroborated by several studies (Pascua, Wulf, & Lewthwaite, 2015; van der Fels, Te Wierike, Hartman, Elferink-Gemser, Smith, & Visscher, 2015). These studies show that while implementing a skill, a performer focuses on factors that affect his performance as well as the entire learning process. As a result, the speed of learning a new activity as well as the efficiency of performing and retaining the skill is influenced by the subject’s focus of attention that is induced by instructions or feedback provided.

Two important loci of focus exist: internal and external. Internal focus aims attention at the body or the specific muscle of the subject while external focus aims attention at the external stimulus that will trigger the performer’s movements. Studies show that attentional focus influences the efficacy of different types of movement, including balance tasks, precision, and motion efficiency (Wulf, 2007; Wulf, 2013). These effects occur as a result of muscular activity that releases maximum force, speed, or endurance (Wulf, 2013). Many studies have been conducted using different theories to evaluate how attentional focus influences the performance of different motor skills since the 1990s (Williams et al., 2015). The theoretical hypothesis was the constrained action hypothesis, which proposed that directing attention to external focus (also referred to as movement upshot) paved the way for an involuntary mode of movement regulation, leading to the attainment of the anticipated upshot as a spinoff. Conversely, when people attempt to micromanage their movements consciously (internal focus), evidence indicates there is a higher likelihood of constraining the motor system by meddling with the process that would otherwise control the synchronization of their movements (Wulf, 2007).
Studies have been conducted to contrast the efficacy of the two forms of attentional foci using different motor skills such as jumping, throwing, balance, golf, and basketball (Wulf, 2007; Oki et al., 2018). Much of the literature indicates that the external focus of attention yields better outcomes for motor performance and learning than the internal focus (Wulf, 2007; Wulf, 2013; Zachry et al., 2005; Mohammadabad & Shahbazi, 2017). The benefits of external focus apply to a wide range of skills and levels, which have been established in young adults, children, in addition to individuals with physical insufficiencies. These factors are also known to determine reaction time, which is the time required for an individual to respond to a stimulus or event. Conversely, other studies have tweaked the subjects’ attentional focus through instructions and feedback (Brown & Ferrigno, 2014); at least one study found differential effects based on attentional focus, across both motor movement and forcefulness (Oki et al., 2018). Tsetseli, Zetou, Vernadakis, and Michalopoulou (2016) examined the effects of internal and external focus of attention on various participants of game performance in tennis. These included skill implementation, base, and decision making, which were measured using the Game Performance Assessment Instrument (GPAI) in three game conditions. There was a significant improvement in the decision-making skills of the group that received instructions to focus externally. A similar trend was noted for the retention test and it was concluded that decision making could benefit from instructions that target the external focus of control.

Another aspect of peak performance that improved with an external focus of attention was jumping height in physical activity. Wulf, Dufek, Lozano, and Pettigrew (2010) investigated the nervous system activity using EMG and observed that greater jump heights and lower EMG activities were obtained with an external focus of attention compared to the internal focus, further verifying the results of previous studies. Similarly, Hill, Schücker, Hagemann, and Strauß (2017)
demonstrated that the external focus resulted in a better movement economy in endurance sports. Cohn (1991) showed that mental relaxation, similar to an external focus, enhanced peak performance. Brewer, Van Raalte, Linder, and Van Raalte (1991) also reported that an external focus of attention together with positive feedback enhanced peak performance in competitive sports. Many studies from different time periods, using different methods of experimentation, have consistently shown that an external focus leads to greater peak performance. Sarhan (2018) examined the effects of different distances of external attentional focus instructions on learning passing and dribbling in soccer and how these effects differ between learning discrete and continuous motor skills. Results from multiple experiments indicated that internal focus hindered the learning process and delayed any improvement in performance. The author argued that these results support the constrained action hypothesis.

Ille et al. (2013) hypothesized that the progressive impact of the external focus of attention would be noted in the three stages of a race start in skilled and inexperienced athletes. The external focus led to a time saving of 0.09 seconds out of which 0.06 seconds were attributed to the running time and 0.03 seconds to the reaction time. The findings supported claims that an external focus at the pre-movement time influenced the learning of a force-generation task. Attentional focus affected the formulation of movement as well as its implementation. This effect could be explained by several factors that are known to shape reaction time. First, ambiguity concerning the response prolongs the reaction time because it advances the informational processing phase of the response-selection stage. As reported earlier, an increase in response processing prolongs the reaction time due to more sub-constituents that require formulation and instigation. It is presumed that this factor can be affected by attentional focus. The nodal-point hypothesis proposes that an internal focus of attention breaks up the sensorimotor chain in sub-portions, which results in the formulation of two
sub-parts of the action as opposed to a whole functional element. This effect is more pronounced in the motor than the pre-motor reaction time (Christina & Rose, 1985). It was suggested that subjects tried to organize their movement consciously in an internal focus, whereas these movements occurred spontaneously in the external focus. Planned responses are more resource-intensive and slower than spontaneous ones, which explains the faster reaction times in the external focus. Finally, it was suggested that longer reaction times ensued when attention was aligned with the implementation of the response (motor set) in contrast with alignment with the sensory set (impetus). It was also suggested that urging the participant to concentrate on details of response implementation delays response formulation and extends the reaction time. Therefore, an internal focus of control impels subjects to give more attention to the completion of the impending movements, thus attenuating their capacity to respond to the gesture.

In a separate study, Wulf (2013) conducted a 15-year review of attentional focus and motor learning. The outcomes showed that instruction or feedback that prompted the external focus of attention yielded better outcomes in terms of performance and learning in various tasks and skill levels across different age groups. These observations were explained by Prinz’s common coding theory of perception and action, which hypothesized that the brain has a common depiction of insight and action as distal occurrences. Consequently, it is possible to conduct commensurate coding and attain the observed outcomes. The review also examined studies of numerous activities, including balance tasks, golf, basketball, dart throwing, American football, and jumping. The common consensus was that the external focus of attention was more effective than the internal one. These effects are also evident in healthy adults and children as well as elderly populations with Parkinson’s disease. These observations are attributed to the fact that an external focus favors automaticity in movement control. Conversely, focusing on the movements themselves limits the
motor system because the subject tries to wield conscious control over their movements. Employing different focus influences electromyographic (EMG) amplitude and contraction duration (Calatayud et al., 2017). For example, Calatayud et al. (2017) report that a controlled speed state boosted pectoralis normalized EMG (nEMG) by 6% and the triceps muscles nEMG by 4% as opposed to a regular focus state. Using different focuses did not affect the nEMG during the explosive speed condition. Therefore, using an internal focus to augment EMG amplitude is only effective under a controlled speed.

**Warm-Up**

It has been acknowledged that warm-up has a positive effect on athletes’ performance as well as their overall physical state. Although it is sometimes assumed that warm-up may lead to a decrease in muscle power or strength, Sim, Byun, and Yoo (2015) found that there was no such a link, and warm-up did significantly enhance athletic performance. However, it is important to ensure the implementation of effective warm-up and post-warm-up strategies as the interval between the warm-up and the activity cannot be too long (Silva, Neiva, Marques, Izquierdo, & Marinho, 2018). Altavilla, Di Tore, and D’Isanto (2018) also emphasized the importance of the interval between warm-up and further activity stating that this period should not be longer than five minutes. In order to maintain muscle temperature after the warm-up, the utilization of warming garments is essential.

Recent research on the outcomes of warm-up suggests that both active and passive warm-up contributes to optimal performance due to its psychological and neural effects, metabolic impact, and temperature increasing effect (McGowan, Pyne, Thompson, & Rattray, 2015). Researchers also identify the third type of warm-up, which is a combination of active and passive warm-up. This type of warm-up has a positive influence on the physical and mental state of the
athlete (Gogte, Srivastav, & Miyaru, 2017). There is also evidence that certain warm-up exercises can have adverse effects on the athlete’s further performance (Walsh, 2017). For example, stretching should be performed dynamically to achieve the highest potential. Warm-up is an important part of physical activity that intensifies the work of muscles and enables athletes to achieve the most prominent results during the game or competition.

In addition to attentional focus, it is possible that warm-up strategies can influence information processing and reaction time. Studies indicate that warm-up has an overall positive effect on people’s physical and psychological states (Frikha, Chaâri, Gharbi, & Souissi, 2016). Warm-ups improve blood circulation and increase the temperature of muscles, which is critical for enhancing performance and preventing injuries. Regarding the mental aspect, warm-ups lead to psychological stability and preparedness for, as well as overall confidence in, performance (Kendall, 2018). Recent studies have shown that cognitive performance is improved following light-moderate exercise compared to intense exercise (Lambourne & Tomporowski, 2010). Studies have shown that warm-up or acute exercise can improve reaction time, inhibitory control, memory, attention, and other aspects of executive function (Tomporowski, 2003; Roig et. al, 2013; Ludyga et al., 2016). Another study by McCrory, Ackermann, and Halaki (2015) have found that different types of warm-ups have diverse or even no effect, their results indicate that it is essential to choose the most effective exercise to prepare athletes for productive training and excellent performance. For example, studies have shown that moderate intensity exercise can improve executive function and higher intensity exercise may improve information processing (Chang et. al, 2011). The link between warm-ups and central processing via cognitive function is well-established in the literature (Chang et al., 2012; Magill & Anderson, 2017). Kendall showed that short periods of exercise can improve motor functions and information processing through a significant reduction
in pre-motor time via central processing (2018). In addition to central processing and cognitive function, some studies have examined the associations between warm-up or acute exercise and peripheral processing and motor functions. There is evidence that acute exercise can reduce motor time through muscle activation, thereby influencing peripheral processing (Audiffren et al., 2008; Sanders, 1983). However, the potential role of warm-up on peripheral processing remains unclear and warrants further research.

Warm-up and attentional focus have also both been linked to fatigue. It has been found that warm-ups can have a twofold impact on performance and fatigue (Salgado, Ribeiro, & Oliveira, 2015). On the one hand, these activities may lead to fatigue, especially when conducted improperly. Silva and colleagues (2018) noted that intensive warm-ups combined with a short period of rest lead to better performance and delayed fatigue, which is specifically apparent in team sports. Increased attention has been associated with a higher degree of fatigue, especially when it comes to some types of focus. For instance, a low level of focus on the relevant aspects of tasks has been associated with higher performance and delayed or less intensive fatigue. The focus on irrelevant components of the task leads to increased fatigue and lower performance (Bertollo et al., 2015). It is pivotal to make sure that athletes carry out warm-ups properly (with definite intensity and intervals) to enhance performance and learning while decreasing and delaying fatigue. Attention focus is another important aspect to consider as athletes’ performance may decrease due to increased fatigue. The literature suggests that there is a link between attention focus, warm-up, and performance, and this research investigated this relationship further.
Summary

Previous studies have shown that external focus of attention decreased reaction time by increasing central processing speed, compared to internal focus of attention. The research suggests that there is a direct link between attentional focus and information processing. It is also well-documented that warm-up or moderate exercise increases the central or cognitive processing speed even though no consistent finding on the latency of the muscle activation. However, there is little research on the potential role of warm-up on central or peripheral processing linked with attentional focus.
Chapter 3. Experiment One

The first experiment aimed to investigate the relationship between attentional focus and information processing, specifically central and peripheral processing. It was examined by comparing internal and external attentional focus impacts on fractionated reaction time (pre-motor time and motor time) using between-group design and the upper extremity.

Method

Participants

The experiment involved 22 right-handed college students from an urban university. Participants’ ages ranged from 18-35 years old with the equal number of males and females. They were not familiar with the task before the experiment. All participants were free from neurological conditions, vision problems, and injury to their dominant-side upper extremity. The study was approved by the Institutional Review Board and an informed consent form was signed before the experiment.

Apparatus

The experiment was conducted on a customized data acquisition system integrating a Biopac MP100 system, a serial response box with a hand switch, and E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA), together with a Windows computer and two 21” monitors. The BIOPAC Systems pre-gelled EL503 electrodes were used to collect the surface EMG signals on the lateral muscle of the triceps of the right arm (see Figure 9). Reaction time was measured using E-Prime 2.0 software, and fractionated RT was determined by Acqknowledge from the BIOPAC system.
All participants were seated at a table with a hand switch on the right side of the body. The 21” monitor was positioned on the table, 33” from the participant. Figure 10 illustrates the testing layout. The task was to depress the hand switch with the right hand, by the extension of the right triceps as quickly as possible after the presentation of a visual stimulus (a green circle on the computer screen). After each response, reaction time was provided to participants as feedback.
Procedure

Participants were randomly assigned into two groups, based on different types of attentional focus (external vs internal). Each subject sat on an adjustable-height chair placed in front of a standard table. The principal investigator explained the tasks and present the proposed visual stimuli to all participants before performing the experiment. As shown in Figure 11, Each trial was initiated by the presentation of a red circle (“ready”) for 1000 ms. The red circle was generated by E-Prime also triggered the start BIOPAC EMG data collection. This was followed by a yellow circle for a 2500 ms duration, which served as “warning.” Lastly, participants were presented with a green circle as the primary visual stimulus for the task. In between each of the 8 trials, participants were presented with a white screen for 1000ms. Figure 11 presents a diagram outlining the visual stimuli procedure.

Participants in the external focus group will instructed to, “Focus on pressing the key as soon as you see the green circle.” Participants in the internal focus group were instructed to, “Focus on extending your elbow as soon as you see the green circle.” All groups completed 6 blocks of practice, each consisting of 8 trials with 60s interval between blocks. At the beginning of each block, participants read instructions for the trials and pressed a key to indicate that they were ready to begin the block.
Data Collection and Statistical Analysis

The interested dependent variables were reaction time (RT), pre-motor time (PMT), and motor time (MT). RT was collected by E-Prime software while PMT and MT were determined by the sEMG signals on the BIOPAC system. RT represented the interval between the stimulus (green circle) and the initial depressing movement. MT represented peripheral processing time, the time from the initial muscle potential to the initiation of movement. PMT represented central processing time, the interval from the presentation of the stimulus to the initial impulse in the sEMG through trial-to-trial analysis on the AcqKnowledge software.

For analysis, mean timing values were calculated per block which allowed for a more accurate evaluation of performance without trial-to-trial variability. Mean RT, PMT, and MT were utilized for statistical analyses. The independent variables were attentional focus as the condition, and block as repeated measures. A 2 (Attentional Focus) x 6 (Block) mixed ANOVA with repeated measure on Block was utilized as the primary analysis. All statistical analyses were conducted on
SAS Windows (SAS Institutes, Inc., Cary, NC). Statistical significance was set as alpha at the 0.05 level.

Results

Analyses were conducted separately by dependent variables: RT, PMT, and MT. Table 2 displays means for the dependent variables across the two conditions of attentional focus (external and internal focus).

**TABLE 2**

*Reaction Time Means for Dependent Variables (RT, PMT, MT) by Condition (Attention Focus)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Attention focus</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>External focus <em>(n=11)</em> (Mean ± SE)</td>
<td>Internal focus <em>(n=11)</em> (Mean ± SE)</td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>247.40 ± 12.35</td>
<td>286.42 ± 11.61</td>
<td></td>
</tr>
<tr>
<td>PMT</td>
<td>167.15 ± 9.71</td>
<td>206.05 ± 10.99</td>
<td></td>
</tr>
<tr>
<td>MT</td>
<td>84.89 ± 9.10</td>
<td>82.29 ± 6.07</td>
<td></td>
</tr>
</tbody>
</table>

**Reaction Time (RT)**

To determine differences in RT, a 2 (Attentional Focus) x 6 (Block) mixed ANOVA with repeated measures on Block demonstrated a main effect on attentional focus for RT, \( F (1, 20) = 7.77, p < .05 \). As a post hoc test, Duncan's MRT indicated external focus (M=247.4, SE=12.35) produced faster RT relative to internal focus (M = 286.42, SE = 11.61), with an overall \( R^2 = 1.0 \). There was no evidence of significant differences by Block \( [F (5, 100) = 1.25, p = .29] \). There was also no evidence of a significant interaction effect, \( F (5, 100) = .72, p = .61 \). Figure 12 illustrates RT across blocks, by condition.
Pre-motor Time (PMT)

The analysis for PMT involved a 2 (Attentional Focus) x 6 (Block) mixed ANOVA, with repeated measures on Block. There was evidence of a significant difference for PMT by attentional focus, $F(1, 20) = 10.28, p < .01$, with an $R^2 = 1.0$. External focus ($M= 167.16, SE=9.71$) demonstrated shorter reaction time compared to internal focus ($M=206.05, SE=10.99$), as indicated by Duncan’s multiple range test. There was no significant difference by Block [$F(5, 100) = .69, p = .63$] or the block by condition interaction [$F(5, 100) =1.38, p = .23$].

Motor Time (MT)

Similarly, to examine differences in motor time, a 2 (Attentional Focus) x 6 (Block) mixed ANOVA with repeated measures on Block was utilized. There was no significant main effect on attentional focus for MT, $F (1, 20) = 0, p = .99$, with an $R^2 = 1.0$. It indicated there was no significant difference on motor time between external focus ($M=84.89, SE=9.10$) and internal focus ($M=82.29, SE=6.07$). The analysis failed to find differences by Block, $F (5, 100) = .65, p =
.66. There was also no evidence of an interaction between block and condition, $F (5, 100) = .57, p = .73$. Figure 13 displays results from PMT and MT across blocks, by condition.

Figure 14. Attentional Focus and Fractionated Reaction Time across Blocks
Chapter 4. Experiment Two

The second experiment aimed to investigate the impacts of attentional focus and warm-up on information processing, including central and peripheral processing. Unlike the first experiment, Experiment 2 used within-subjects design to test the effects of attentional focus on fractionated reaction time (pre-motor time and motor time) on the lower extremity. Also a warm-up protocol was used to determine whether warm-up exercise benefited information processing compared to the controlled without warm-up.

Method

Participants

Experiment 2 involved 24 participants (age: 18-35 years old, all males) with the right foot as their dominant side from an urban university. Participants were free from any neurological conditions, stroke, blindness, and injury to do the warm-up protocol and the experimental task. The study was approved by the Institutional Review Board at Wayne State University. An informed consent was signed prior to their participation.

Apparatus

The experiment was conducted on a customized data acquisition system integrating a Biopic MP100 system, serial response box with foot pedal, and E-Prime software (Psychology Software Tools, Pittsburgh, PA), together with a Windows computer and two 21” monitors. The Biopic pre-gelled EL503 electrodes were used to collect the surface EMG signals on the lateral gastrocnemius (GAS) and tibialis anterior (TA) muscle of the right leg (Figure 13). Reaction time was measured using E-Prime 2.0 software, and fractionated RT was determined by Biopac system with Acqknowledge 3.8.
Task

All participants sat at a table with a foot pedal on the right front of the body (see Figure 15). Figure 16 shows a detailed picture of the footswitch. A computer monitor was positioned on the table 26” from the participant. The task was to depress the pedal by the plantar flexion of the right foot as quickly as possible after the presentation of a visual stimulus (a green circle on the computer screen). After each response, reaction time was provided to participants as feedback.

Figure 15. Placement of the electrodes over the Tibialis anterior muscle

Figure 16. Testing area layout for Experiment 2
Procedure

Participants were randomly assigned into two groups, based on whether or not they were required for the warm-up protocol. In the warm-up group, participants were asked to do the warm-up protocol (Figure 16). Before starting the experimental task, the principal investigator explained the tasks and presented the proposed visual stimuli to all participants. Participants were directed to focus on the pedal during the external focus (EF) condition and on the plantar flexion of the foot during the internal focus (IF) condition. A focus-related instruction was presented on the screen before each test (see Figure 18). The on-screen instruction for internal focus was “Focus on plantar flexion of your foot as soon as you see a green circle.” Conversely, the on-screen instruction of external focus was “Focus on depressing the pedal as soon as you see the green circle.” The circles were generated by E-Prime and the red circle was also used as a trigger to start BIOPAC’s EMG data collection. The reaction time was then measured following the appearance of the visual stimuli by the software. Both participants in the warm-up group and the non warm-up groups completed this simple RT task for 4 blocks (8 trials each) of each attentional condition, with counter-balanced order.
Warm-up protocol: Participants in the warm-up group were asked to conduct a general and lower body warm-up prior to their participation in the task. The warm-up consisted of a total of 15 minutes (Figure 17). Specifically, participants were asked to jog lightly or walk briskly on a treadmill for 5 minutes. This was followed by 8 exercises (45 seconds on, 15 seconds rest each), including left hip, right hip, side to side glide and reach, wax on, wax off, plie squats, swinging squats, split squat right, and alternating curtsy squats. A trained researcher supervised all warm-up activities and participants were provided with a video of the exercises to follow along. The warm-up routine ended with 2 minutes of cool down stretches.
**Exercise Routine - 13 minutes total**

1. Left Hip
2. Right Hip
3. Side to Side Glide and Reach
4. Wax On, Wax Off
5. Plie Squats
6. Swinging Squats
7. Split Squat Right
8. Alternating Curtsy Squats
   -- 45 second of exercise and 15 seconds of rest
   -- 1 sets of each exercise

**Cool Down Stretches - 2 minutes total**

---

**Data Collection and Statistical Analysis**

The dependent variables were reaction time (RT), pre-motor time (PMT), and motor time (MT). RT was collected by E-Prime software while PMT and MT were determined by the sEMG signals with BIOPAC’s acqKnowledge software.

The results were evaluated using mixed ANOVA with repeated measures. First, a 2 (Group: Warm-up vs. non Warm-up) by 2 (Focus: External vs. Internal) by 4 (Block) mixed ANOVA with repeated measures (on Focus and Block) was conducted to examine the impact of attentional focus on fractionated reaction for the lateral gastrocnemius (GAS). This analysis was repeated for fractionated reaction time of the tibialis anterior (TA) muscle. All the data were analyzed with SAS Windows. An alpha level of 0.05 was accepted as significant.

**Results**

Results were presented for the reaction time first, followed by the fractionated reaction time on GAS and TA muscles, respectively. Dependent variables (RT, MT, and PMT) were
examined by groups, attentional focus conditions, and practice blocks. Table 3 displays means and standard error for the dependent variables across the two groups (warm-up and non warm-up) and two focus conditions (external and internal focus).

**TABLE 3**

*Reaction Time Means for Dependent Variables (RT, PMT, MT) by Groups and Condition*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group x Condition</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NWP-External</td>
<td>NWP-Internal</td>
<td>WP-External</td>
<td>WP-Internal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(n=12) (Mean ± SE)</td>
<td>(n=12) (Mean ± SE)</td>
<td>(n=12) (Mean ± SE)</td>
<td>(n=12) (Mean ± SE)</td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>283.81 ± 6.28</td>
<td>342.04 ± 7.95</td>
<td>296.20 ± 2.92</td>
<td>345.03 ± 4.99</td>
<td></td>
</tr>
<tr>
<td>PMT on GAS</td>
<td>179.72 ± 6.41</td>
<td>212.11 ± 5.18</td>
<td>227.06 ± 3.14</td>
<td>260.86 ± 5.20</td>
<td></td>
</tr>
<tr>
<td>MT on GAS</td>
<td>104.09 ± 3.43</td>
<td>129.19 ± 4.68</td>
<td>69.39 ± 1.78</td>
<td>84.17 ± 4.05</td>
<td></td>
</tr>
<tr>
<td>PMT on TA</td>
<td>201.57 ± 5.91</td>
<td>234.45 ± 5.61</td>
<td>236.12 ± 3.45</td>
<td>271.51 ± 4.76</td>
<td></td>
</tr>
<tr>
<td>MT on TA</td>
<td>82.24 ± 3.50</td>
<td>107.60 ± 4.16</td>
<td>60.34 ± 1.84</td>
<td>73.81 ± 4.17</td>
<td></td>
</tr>
</tbody>
</table>

Note: NWP = no warm-up, WP = warm-up

**Reaction Time**

A 2 (Group: Warm-up vs. non Warm-up) x 2 (Focus: External vs. Internal) x 4 (Block) mixed ANOVA with repeated measures on Focus and Block revealed a significant main effect on attentional focus for RT, F (1, 154) = 128.14, p<.01, with an overall $R^2 = 1.0$. But the analysis did not find differences on warm-up group [F (1, 22) = 0.5, p = .49], Block [F (3, 154) = 0.49, p = .69], or any interactions [p > .05]. Duncan’s Multiple Range Test indicated external focus led to a significantly faster reaction time (M = 290.01) compared to internal focus (M = 343.54). Figure 20 illustrates RT across blocks, by group and condition.
Fractionated RT on GAS Muscle

On the GAS muscle specifically, the three-way mixed ANOVA analysis showed main effects on warm-up group \( [F (1,22) = 29.79, p< .01] \) and attentional focus \( [F (1, 154) = 68.50, p<.01] \) for PMT. There was no difference on practice block \( [F (1, 154) = 0.07, p>.05] \) or any interaction for PMT. Duncan’s Multiple Range Test indicated that pre-motor time of the GAS muscle was significantly faster for the non warm-up group (\( M = 195.92 \)) than warm-up group (\( M = 243.96 \)). In addition, Duncan’s MRT found that external focus (\( M = 203.39 \)) produced significantly faster PMT than internal focus (\( M = 236.49 \)). Figure 21 illustrates PMT across blocks, by group and condition.
Similarly, there were significant main effects of group [F (1, 22) = 65.81, p < .01] and attentional focus [F (1, 154) = 35.40, p < .01] for MT on GAS. There was no difference in practice block [F (1, 154) = 1.23, p > .05] or any interaction for MT on GAS. Duncan’s Multiple Range Test indicated that motor time of the GAS muscle was significantly faster for the warm-up group (M = 76.78) than the non warm-up group (M = 117.01). In addition, Duncan’s MRT found that external focus (M = 86.74) produced significantly faster MT than internal focus (M = 107.05). Figure 22 illustrated MT across blocks, by group and condition.
Fractionated RT on TA Muscle

On the TA muscle specifically, the three-way mixed ANOVA analysis showed main effects on group \( [F (1,22) = 14.74, p< .01] \) and attentional focus \( [F (1, 154) = 69.49, p<.01] \) for PMT. There was no difference on practice block \( [F (1, 154) = 0.13, p>.05] \) or any interaction for PMT. Duncan’s Multiple Range Test indicated that pre-motor time of the TA muscle was significantly faster non warm-up group (M = 218.01) than warm-up group (M = 253.81). In addition, Duncan’s MRT found that external focus (M = 218.85) produced significant faster PMT than internal focus (M = 252.98). Figure 23 illustrates PMT across blocks, by group and condition.
The analysis on MT revealed that there were significant main effects of group \([F (1, 22) = 34.39, p < .01]\) and attentional focus \([F (1, 154) = 33.83, p < .01]\) for MT on TA. There was no difference on practice block \([F (1, 154) = 1.38, p > .05]\) or any interaction for MT on TA. Duncan’s Multiple Range Test indicated that the warm-up group (M = 67.08) had significantly faster motor time of the TA muscle than the no warm-up group (M = 94.92). In addition, Duncan’s MRT found that external focus (M = 71.29) produced significant faster MT than internal focus (M = 90.70). Figure 24 illustrates MT across blocks, by group and condition.
Chapter 5. Discussion

This research aimed to determine the effects of attentional focus and warm-up on the peripheral (MT) and central (PMT) components of fractionated reaction time. For this purpose, two different types of software (E-Prime 2.0 and AcqKnowledge) were programmed to fully integrate, allowing for millisecond timing precision and temporal syncing of the reaction time (RT) and surface electromyography (sEMG) data. Fractionated reaction time consisted of two components: pre-motor time, which is directly influenced by central processing, and motor time, which is a result of peripheral activation. Two different experiments (Experiments 1 and 2) were carried out to test five hypotheses on attentional focus, warm-up, and fractionated reaction time.

Attentional Focus

Attentional focus generally consists of two types of focus: internal focus and external focus. An external focus of attention involves focusing on a movement outcome or environmental object; in our experiments, this external focus was to direct attention to a hand switch in Experiment 1 and a foot pedal in Experiment 2. The internal focus of attention involves focus on a specific body movement or the muscle actions involved in the movement. In Experiment 1, participants were instructed to focus on their right elbow extension by contracting their right triceps as internal focus condition. Similarly, the internal focus in Experiment 2 was to direct attention to the right plantar flexion by contracting the right gastrocnemius. Based on the previous literature and theory, this research hypotheses predicted that attentional focus would affect fractionated reaction time and that external focus of attention would produce faster reaction times especially pre-motor component than internal focus of attention.

The results of Experiment 1 supported Hypothesis 1 and Hypothesis 2 on attentional focus. Specifically, we confirmed that attentional focus affected reaction time, with external focus of
attention improving reaction time when compared to internal focus. The results also showed that the main effect was on central processing speed was affected by external focus of attention, instead of muscle activating latency. External focus led to faster pre-motor reaction times compared to internal focus. There was no significant difference in motor reaction time when comparing external and internal focus, further highlighting the importance of central processing in improving reaction time. The EMG findings evaluated the reduction of muscle activation time (PMT) and showed that motor commands moved faster to the muscle under the external attentional focus as opposed to the internal focus condition. This finding implied that the planning of movement yields better outcomes when the focus of attention is directed externally. An external focus of attention expedites the modus operandi while an internal focus engrosses the participants in a deliberate “unnatural” style of motion control that can interfere with automatic processes.

Experiment 2 involved a more complicated research design, where participants were divided into attentional focus groups as well as warm-up and no warm-up conditions. In this experiment, participants utilized their right foot to depress the pedal after the presentation of a visual stimulus. This is a different movement than experiment 1, where participants were instructed to perform an elbow extension. The elbow extension primarily involved the triceps and was a relaxing position of the muscle prior to action. In the second experiment, participants were instructed to perform foot plantar flexion, with the lateral gastrocnemius as the prime mover.

The results from attentional focus alone confirmed the results in Experiment 1 and the first two hypotheses. External focus of attention produced significantly faster reaction time than internal focus of attention with the two muscles (lateral gastrocnemius and tibialis anterior) of the right leg. In fact, for reaction time, attentional focus was the only variable that showed a significant
difference. The results also confirmed Hypothesis 3, that attentional focus effects would be independent of different research designs and muscle effectors.

Contrary to experiment 1 where the effect of attentional focus was seen primarily through significant differences in pre-motor time, experiment 2 also demonstrated significant differences in motor time by attentional focus. The motor time for the GAS muscle and the TA muscle were both significantly faster with external focus of attention. There are several potential reasons for this: first, as previously discussed, the experimental procedure involved foot flexion as opposed to elbow extension, and the different muscle movements could have influenced the outcome. Studies have shown that increased complexity of movement, including the number of muscles moving, the need for movement precision, and the interval of the movement involve greater synchronization of more neuromotor actions, which elongates the time needed for neurologic arrangement thus leading to longer reaction times. Thus, movement of the foot has a generally slower reaction time than movement of the arm. But this effect is more pronounced in the motor than the pre-motor reaction time (Christina & Rose, 1985). The increased complexity of muscle movement from experiment 1 to experiment 2 could have influenced the role of attentional focus on motor time. This further supports the hypothesis that attentional focus is significantly related to reaction time, with evidence of its potential to influence both motor time and pre-motor time.

Warm-Up

Experiment two focused on testing the effects of attentional focus and warm-up by comparing participants across both warm-up and non-warm up groups, along with two conditions of attentional focus. In Hypothesis 4, we predicted that warm-up would lead to significantly increased information processing speeds, in both central and peripheral processing, when compared to no warm-up. This hypothesis was not supported by the results of experiment two.
There was no evidence of a significant difference in reaction time between warm-up groups and warm-up alone had a null effect.

When considering attentional focus and warm-up together, there was evidence of a significant difference in motor time; the warm-up group showed significantly faster motor reaction time than the no warm-up group on both the GAS and TA muscles. Conversely, the no warm-up group showed significantly faster pre-motor time than the warm-up group. External focus of attention also consistently produced faster results, although when combined with warm-up, the effect was shown primarily in motor-time, indicating a primary impact on peripheral activation latency. When combined with warm-up, the effect on pre-motor time, or central processing, was not significant. It is possible that the shift in study design, from a within-group design in Experiment 1 to a between-group design in Experiment 2, influenced these results.

Previous studies have shown that warm-up (or brief exercises) improve motor time via muscle activation, but may not influence pre-motor time (Audiffren et al., 2008; Sanders, 1983). More recently, Kendall (2018) demonstrated a significant reduction in PMT after acute exercise and a non-significant reduction in MT. The results of experiment two further confirmed those findings. Participants who did not engage in warm-up activities showed significantly faster pre-motor time but slower motor time. Warm-up activities, or acute exercise, thus primarily influenced motor time and peripheral activation latency and may influence central processing speed. Other investigators have identified alertness as a key factor influencing pre-motor processing (Magill, & Anderson, 2010); specifically, reaction time increases as a function of alertness and vigilance (long-term maintenance of alertness). Individuals who must wait longer for the start signal of a task become less alert and less vigilant. For experiment two, individuals in the groups that did not warm-up may have simply been more alert and vigilant at the time of the task, given that they did
not spend 15 minutes prior in a warm-up activity. In addition to alertness, fatigue from the warm-up activity may also have influenced pre-motor processing speeds. While the warm-up activity appears to have improved motor reaction time and peripheral activation, studies have shown that warm-up may have a twofold impact on performance and fatigue (Salgado, Ribeiro, & Oliveira, 2015). Thus, warm-up may increase fatigue and reduce performance through central processing, while simultaneously improving peripheral activation latency. Further studies examining warm-up and fractionated reaction time are warranted, given that few of the cited studies rely on the innovative methods presented here with E-prime precision and real-time sEMG.

Overall, attentional focus remained the strongest independent predictor of reaction time, with external focus of attention consistently demonstrating faster reaction times than internal focus of attention, regardless of warm-up. This research provides an important contribution to the literature on attentional focus, warm-up, central and peripheral processing, and motor movements. Prior research has shown that the accuracy and quality of movements are determined by the performer’s focus (Pascua, Wulf, & Lewthwaite, 2015; van der Fels, Te Wierike, Hartman, Elferink-Gemser, Smith, & Visscher, 2015). Our findings were consistent with Kovas et al. (2018), where external cues were found to produce faster RT compared to internal focus in a field setting with sprinters. The investigators also found no significant differences in motor time, indicating that pre-motor reaction time likely played a larger role. The authors concluded that differences in reaction time were likely related to the shortening of central processing time. Similarly, other studies have shown that decreases in reaction time are primarily due to reductions in pre-motor time (Pouchelle et al., 2003). Collectively, our findings and those of previous studies indicate that external focus has a particular impact on the pre-motor reaction time due to increased speed in central processing.
There is a need for further investigation of the effects of warm-up on attentional focus. These results shed some light on the issue, but since warm-up is so heavily utilized among athletes and in sports, it is important to further understand how warm-up combined with external focus of attention can be used to enhance reaction time and athletic performance.

Limitations

This research involves well-planned and executed experimental designs, but some limitations exist. First, the information provided by participants on their overall health and well-being was not confirmed beyond their self-report. Second, participants may have engaged previously in similar exercise, practice, or reaction time training. The participants in Experiment 1 primarily consisted of athletes or those interested in sports. Due to the onset of the COVID19 pandemic during the period of Experiment 2, the participants were more diverse in terms of athletic ability and health. Another important limitation was that experiment 1 was conducted with the upper body and experiment 2 was conducted with the lower body. While this difference in research design helped confirm results on attentional focus across different experiments, it is important to note that the lower body has generally slower reaction times than the upper body. The monitor was set to a refresh rate of 60hz which, although unlikely, may have influenced some participants.

Summary

This research involved five hypotheses on the relationships between attentional focus, warm-up, and fractionated reaction time. Through Experiment 1, we found that external focus of attention facilitated information processing speed, specifically for the central component but not the peripheral component (muscle activation latency) relative to movement focus. In Experiment 2, we found that the effects of attentional focus for both the central and peripheral processing with external focus resulted in faster reaction, premotor time, and motor time compared to internal
focus. Collectively, attentional focus effects were independent of the research designs and the muscle effectors. However, the experiment revealed mixed evidences for the role of warm-up on information processing; warm-up activities enhanced speed for motor-time, but reduced speeds for premotor time, resulting in a null effect overall on reaction time. Further research that includes warm-up and attentional focus is needed in the future.

These findings can be applied in numerous contexts, including for the improvement of the execution of simple tasks and in competitive sports. Research has shown that most athletes focus internally when beginning competitions and that their coaches generally recommend internal focus (Porter et al., 2010). Warm-up activities are also very common in athletic sports. Thus, coaching methods in competitive sports can be adapted and information can be provided to athletes to compel them to focus externally when competing to assist them in improving their starting time.

Despite the strong results, it is uncertain whether similar outcomes can be achieved when an external attentional focus is applied in complex scenarios. Therefore, there is a need to replicate the procedure using a complex activity involving more than one joint to ascertain whether the same observation holds for multifaceted actions. Further research on other types of stimuli, such as audio stimulus, may also be warranted, particularly for applications in competitive sports. Additionally, since there were no significant differences in motor time in the first experiment, future research should involve investigations into factors that influence improved motor reaction time.

Further research should also focus on diverse samples, as different cohorts may have physiological and anatomic peculiarities that have an impact on their learning abilities. It is important to investigate fractionated reaction time in different groups based on gender, age (children or older people), and cross-culturally.
NOTICE OF IRB APPROVAL
IRB-20-03-1928-B Expeditied/Exempt Review EXPEDITED

DATE: June 09, 2020
TO: Aljashi, Mohammed, Kinesiology Health & Sports Studies
McCaughtry, Nate, Kinesiology Health & Sports Studies
FROM: Miller, Scott, Professor, BS Expeditied/Exempt Review
PROTOCOL TITLE: Effects of Working and Attentional Focus on Performance of Central and Peripheral Processing
FUNDING SOURCE: NINSI
PROTOCOL NUMBER: IRB-20-03-1928
APPROVAL PERIOD: Approval Date: June 05, 2020, Expiration Date: June 04, 2023

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 (IRB) for the period of June 05, 2020 through June 04, 2023. This approval does not replace any departmental or other approvals that may be required.

The following attachments and consent/assent documents have been reviewed and approved by the IRB for the approval period noted above.

Notes:
Note to PI: This submission was reviewed under the IRB Administration Office Flexible Review and Oversight Policy, therefore the expiration date is 06/04/2023.

Protocol/Proposal/Dissertation (received 05/26/2020)
Behavioral Research Informed Consent (dated 03/04/2020)
Recruitment Script

Medical records are not being accessed therefore HIPAA does not apply.

Attachments

Research Design
Description Protocol - 2020
updated_protocol_summary_form_revision_updated_4_2019
Recruitment Script Ms
APPROVED Recruitment Script Ms
APPROVED Updated Informed Consent - February 07, 2021
Signature
Mohammed C.V update

*You may receive a "Continuation Renewal Reminder" approximately three months prior to the expiration date; however, it is the Principal Investigator's responsibility to obtain review and continued approval before the expiration date (See the IRBs PI Responsibility Policy). Data collected during a period of lapsed approval is unapproved research and can never be reported or published as research data.

Page 2
67

* All changes or amendments to the above referenced protocol require review and approval by the IRB BEFORE implementation.

* Adverse Reactions/Unanticipated Problems ARE TO be submitted on the appropriate form within the time frame specified in the IRB. In the event of an unexpected problem use the Unanticipated Problem Report Form.

Note: Studies conducted at DMC sites or DMC medical record used for affiliate review. Authorized DMC personnel have been added to this submission under Personnel Information "Other".

Administration Office Policy: www.irb.wayne.edu/policies-human-research

NOTE: Upon notification of an impending regulatory site visit, hold notification, and/or external audit the IRB Administration Office must be contacted immediately. Also notify the IRB of any changes to the funding status of the above referenced protocol. In the event of an unexpected problem use the Unanticipated Problem Report Form.

To view stamped documents associated with this approval, please see the Protocol Information- Attachments section-IRB Initial Approval Stamped Documents.

COVID-19 NOTE to PI: Minimal Risk Research: Due to the COVID-19 health crisis all minimal risk research that includes in-person interaction must be paused. See HRFP-IRB COVID-19 Guidance at research.wayne.edu/coronavirus. Research conducted remotely without direct person to person contact may continue as per the IRB approved protocol. For studies in which the research design allows for modification to remote contact (phone interview, online surveys, etc.) that modification must be submitted to the IRB for review and approval via an amendment. If the research design does not lend itself to remote research activities the research must pause and the study must be placed on hold. This hold must be reported to the IRB at the next routine amendment and also indicated for the next continuing review (if applicable). If modifications of research activities are conducted before IRB review and approval an Unanticipated Problem must be submitted to the IRB Office.

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APPENDIX B. INFORMED CONSENT

Attentional Focus and Warm-Up on Reaction Time

Behavioral Research Informed Consent

Title: Effects of Warm-Up and Attention Focus on The Performance of Central and Peripheral Processing

Principal Investigator (PI): Mohammed Aljaini
41564 Boulder Creek Dr, Canton, MI 48188
(330) 891-7747

KEY INFORMATION

1. Participation is voluntary.
   Taking part in this study is voluntary. You have the right to choose not to take part in this study. If
   you decide to take part in this study, you can later change your mind and withdraw from the study.
   You are free to only answer questions that you want to answer. You are free to withdraw from
   participation in this study at any time. Your decision will not change any present or future
   relationship with Wayne State University or its affiliates, or other services you are entitled to receive.

2. Summary of the research
   You are being asked to participate in a research study about the effects of adopting different focus of
   attention and warm-up activities on the learning outcome of motor skills. Your participation will
   involve one visit lasting at most 30 minutes.

3. Reasonable foreseeable risks or discomforts
   Risks in this study are minimal. Participants will not be at any physical risk while performing the
   task. However, although every attempt will be made to protect your data, it is possible that
   unauthorized persons could gain access. To minimize the risk of breach confidentiality, all informed
   consent forms will be locked in a cabinet at the Motor Behavior Lab. The data will be stored in a
   computer in the lab and there is no link between data and identifiers.

4. Reasonable expected benefits
   As a participant in this study, you will not gain any direct benefits. However, the results of this study
   may help to increase knowledge and understanding about motor learning techniques.

5. Alternative procedures or course of treatment
   This research study does not include an alternative procedure or course of treatment.
Attentional Focus and Warm-Up on Reaction Time

Purpose:
You are being asked to participate in a research study about the effects of adopting different focus of attention and warm-up activities on the learning outcome of motor skills because you are a Wayne State student that is physically healthy, free from any neurological conditions, stroke, blindness, and injury and fall in the range of 18 and 30 years old. This study is being conducted at Wayne State University in 10 Old Main, Motor Behavior Lab. The estimated number of participants to be enrolled in this study is 72. Please read this form and ask questions you may have before agreeing to be in the study. This study is to investigate the impact of attentional focus and warm-up on the premotor and motor components of reaction time.

Study Procedure:
If you agree to participate in this study, you will be assigned to a different group based on muscle movement (arm or leg), warm-up (or no warm-up), and attentional focus (external and internal). Depending on your group, you will participate in either 6 blocks, with 8 trials each or 4 blocks with 8 trials each.

If you are assigned to a warm-up condition, you will participate in 15 minutes of warm-up exercises based on your muscle group (arm or leg). Those in the arm group will do upper body warm-up exercises. Those in the leg group will do lower-body warm-up exercises. After this, you will participate in the primary task of the experiment. If you are not assigned to warm-up, you will not do any exercises and will go straight to the primary task.

For the primary task, you will sit on an adjustable-height chair placed in front of a standard table. The principal investigator will explain the tasks and present the proposed visual and auditory stimuli to all participants before performing the experiment. A focus-related instruction will be presented on the screen before each test, informing you to extend your elbow or press your foot depending on your muscle group. The reaction time will then be measured following the appearance of the auditory or visual stimuli. The total time for the visit will be about 30 minutes.

Benefits
As a participant in this research, you will not gain any direct benefits. However, the results of this study may help to increase knowledge and understanding about motor learning techniques.

Risks
The participants will not be at any physical risk while performing the task. However, although every attempt will be made to protect your data, it is possible that unauthorized persons could gain access. To minimize the risk of breach confidentiality, all informed consent forms will be locked in a cabinet at the Motor Behavior Lab. The data will be stored in a computer in the lab and there is no link between data and identifiers.

Study Costs
Participation in this study will not cost you anything but time.

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

Research Related Injuries
Attentional Focus and Warm-Up on Reaction Time

In the event that this research related activity results in an injury, treatment will be made available including first aid, emergency treatment, and follow-up care as needed. Care for such will be billed in the ordinary manner to you or your insurance company. No reimbursement, compensation, or free medical care is offered by Wayne State University. If you think you have suffered a research-related injury, contact the PI right away at (330) 891-7747.

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 record by 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 Protection (OHRP), Office of Civil Rights (OCR), etc.] may review your records. 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. If you decide to take part in this study you can later change your mind and withdraw from the study. You are free to only answer questions that you want to answer. You are free to withdraw from participation in this study at any time. Your decision 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 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 Mohammed Aljaini or one of his research team members at (330)891-7747. If you have questions or concerns about your rights as a research participant. The Chair of the Institutional Review Board (IRB) 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 (313) 577-1628 to ask questions or voice concerns or complains.

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.
Attentional Focus and Warm-Up on Reaction Time

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).

Wayne State University
Institutional Review Board
Jun 05 2020 - Jun 04 2023

Signature of translator

Date

Printed name of translator

Time
Recruitment Script:

The targeted population to participate in this study is Wayne State University students with good physical health, without any recent injuries. The targeted age group is between 18 and 30 years old. Students with prior experience will be excluded immediately. Personal contact will be the recruitment method for this experiment. The following script will be used mainly to recruit the students after their classes:

“Good morning, my name is Mohammed Aljahni and I am a graduate student at Wayne State University. I would like you to consider helping me in my research by participating in my experiment. The aim of the study is to examine the relationship between people’s focus of attention, warm-up exercises, and their reaction times. We will attempt to determine which, if any, part of reaction time is more affected by attention focus and warm-up. If you agree to participate in this study, you will be randomly assigned (like a rolling dice) to either use your arm or your leg. You will also be assigned to either warm-up or not warm-up. And you’ll be instructed on where to focus before the task. The task is simple; you will push down on a hand switch or foot pedal after seeing a green circle, 8 times in a row, across 4 or 6 rounds. We will measure your reaction time by attaching EMG sensors to your arm or leg and we will share your reaction times with you at the end of each trial.

The total time in experiment will be about 30 minutes. If you are interested in participation or have any questions about my research, please feel free to contact me any time at ge7523@wayne.edu, or (330)891-7747. Thank you for your time.”

The potential participants who demonstrated their interests will be invited to the motor behavior laboratory where they will be presented more details with the equipment that will be used in the research and they will be given an informed consent form. Only those students, who sign the informed consent form can participate in the study.

APPROVAL PERIOD

WAYNE STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
JUN 05 2020 - JUN 04 2023
## APPENDIX C. INFORMATION SHEETS

### INFORMATION SHEET EXPERIMENT 1

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REFERENCES


Bertollo, M., di Fronso, S., Filho, E., Lamberti, V., Ripari, P., Reis, V., … Robazza, C. (2015). To focus or not to focus: is attention on the core components of action beneficial for


ABSTRACT

EFFECTS OF ATTENTION FOCUS AND WARM-UP ON PERFORMANCE OF CENTRAL AND PERIPHERAL PROCESSING

by

Mohammed Aljahni

December 2020

Adviser: Dr. Qin Lai

Major: Kinesiology - Exercise and Sport Science

Degree: Doctor of Philosophy

Previous studies have shown that external focus of attention decreased reaction time by increasing central processing speed, compared to internal focus of attention. The research suggests that there is a direct link between attentional focus and information processing. It is also well-documented that warm-up or moderate exercise increases the central or cognitive processing speed even though no consistent finding on the latency of the muscle activation (peripheral processing). However, there is little research on the potential role of warm-up on central or peripheral processing linked with attentional focus. The first experiment aimed to investigate the relationship between attentional focus and information processing using a between-group research design. Specifically, it examined how internal and external attentional focus affected fractionated reaction time (pre-motor time and motor time) on the upper extremity. Results revealed that external focus of attention significantly decreased reaction time and pre-motor time (central processing) but no effect on motor time (peripheral processing).

The second experiment aimed to investigate the impacts of attentional focus and warm-up on information processing indexed by fractionated reaction time. This experiment utilized a within-subjects design to test the effects of attentional focus on reaction time, premotor time and
motor time on the lower extremity. A 15-min warm-up protocol was used to determine whether warm-up exercise benefited information processing compared to the controlled. Results demonstrated external focus of attention produced significantly faster reaction time, premotor time, and motor time than internal focus. However, the warm-up exercise appeared to have a mixed effect on fractionated reaction time compared to the no warm-up. Specifically, the warm-up decreased motor time, but increased premotor time. In summary, the present research indicated that attentional focus effect was independent of research designs and muscle effectors. External focus of attention could facilitate both the central processing and peripheral processing relative to internal focus. An acute warm-up protocol facilitated the muscle activation, but might cause disruption or inhibition of the central processing. It should be further studied in the future.
AUTOBIOGRAPHICAL STATEMENT

Mohammed Aljahni graduated from King Saud University with a degree in Physical Education in 2011. He earned a Master of Science degree in Sport Coaching from Akron University. He will complete his Ph.D. (magna cum laude) in December 2020 from Wayne State University in Exercise and Sport Science. He also received a degree as a Fitness Specialist in 2009 from King Saud University and a diploma in Football Medicine from FIFA 2020. Prior to embarking on his graduate education, Mohammed was an expert trained physical education and swimming instructor and coach in Saudi Arabia for many years. He won the first-place championship in swimming three times in 2006 and 2007 and the Gulf regional championship (2009). He is certified in First Aid and CPR and swimming instruction.

During his time at Wayne State University, Mohammed has conducted in research in the Motor Behavior Laboratory as research assistant since 2018. He has presented his research at national and local conferences and has received over 50 certifications in various research, academic, and exercise skill areas. Upon completion of his Ph.D., Mohammed has accepted a teaching and research position at Jazan University in the Physical Education department.