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THINKING OUTSIDE THE BLOCK: EXTERNAL FOCUS OF ATTENTION SHORTENS REACTION TIMES IN COLLEGIATE TRACK SPRINTERS

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THINKING OUTSIDE THE BLOCK: EXTERNAL FOCUS OF ATTENTION SHORTENS REACTION TIMES IN COLLEGIATE TRACK SPRINTERS

By Garrett F. Miles

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ABSTRACT

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Reaction time during a sprint start can have a dramatic effect on the outcome of a short-distance running race. While, focusing attention on an external cue has been shown to enhance skill acquisition and performance (Wulf, 2013), track and field coaches tend to provide instructions to their athletes that promote an internal focus of attention (Porter et al., 2010). Therefore, the purpose of this study was to determine whether instructions promoting external versus internal focus of attention would influence reaction time (RT) during a track sprint start task. Additionally, a primary interest was to determine if focus of attention manipulation will influence primarily central processes during movement preparation, or peripheral processes during movement execution. Twelve Division III collegiate track sprinters (ages 18-23) completed three separate testing sessions at least 2 days apart. Reaction times were assessed under three different conditions: i) external focus (EF) where subjects focused on pushing the blocks away; ii) internal focus (IF) where subjects focused on extending the knees; and, iii) no focus instruction (NF). Muscle activity was recorded from the left and right vastus lateralis and left and right medial gastrocnemius muscles. Rear foot RT during the EF condition (Mean=212.11 ms, SE=8.45 ms) was significantly shorter than both IF (Mean=234.21, SE=5.76 ms) and NF conditions (Mean=236.87, SE=8.82). Front foot RT was also significantly shorter during EF (Mean=250.24, SE=17.24 ms), compared to IF (Mean=266.98, SE=16.44 ms) but not shorter than NF (Mean=268.73, SE=14.23 ms). Muscle activity also indicated a shorter premotor RT under the EF condition (Mean=157.75, SE=7.38 ms), compared to IF (Mean=181.90, SE=5.72) and NF (Mean=173.60, SE=7.30 ms). Our findings indicate that adopting an EF improves RT during sprint starts. This improvement likely originates from a reduction in movement preparation time. These findings have the potential to contribute to the development of new coaching techniques when the aim is to improve the reaction time of athletes.

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INTRODUCTION

The start of a short distance running race can have profound effects on the outcome, accounting for approximately 5% of total race time in the 100 m dash (Harland & Steele, 1997). The goal is to accelerate from the starting block in a linear direction as quickly as possible following the reaction to a gunshot, allowing the athlete to reach maximum running velocity as quickly as possible. Therefore, integration of any variable that reduces race time has the potential to benefit these athletes.

In addition to biomechanical and physiological factors, the efficacy of information processes involved in movement preparation and execution could influence the production speed of complex tasks that require a quick response to a stimulus and the coordination of multiple effectors (Ille, Selin, Do, & Thon, 2013). The focus of a performer's attention may be one such factor that could enhance reaction time (RT) during the start of a sprint race.

Two distinct forms of attentional focus that can influence movement output performance have been identified: external (EF) and internal (IF) focus of attention (Wulf, McNevin, & Shea, 2001). An EF requires focusing on the intended movement effect on an implement or the environment, whereas an IF requires the performer to focus on their own body movements (Wulf, 2013). Using standing long jump as an example, a performer may utilize an EF by focusing on jumping as far away from a start line or even jumping to a cone. Conversely, the performer may utilize an IF for this task by focusing on extending the knees as quickly as possible (Porter, Anton, Wikoff, & Ostrowski, 2013). In another example using golf, a performer may utilize an EF by focusing on the position of the club head or use an IF by focusing on the motion of the arms through the swing. Over the last two decades, a considerable amount of research has demonstrated that an EF, compared to an IF has beneficial effects on motor learning and performance. These benefits have been seen in a multitude of tasks including dynamic balance tasks (McNevin, Shea, & Wulf, 2003; Shea & Wulf, 1999; Jackson & Holmes, 2011; Wulf, Weigelt, Poulter, & McNevin, 2003), throwing (Southard, 2011), golf shots (Bell & Hardy, 2009; Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007), soccer kicks (Wulf, McConnel, Gartner, & Schwarz, 2002), baseball batting (Castaneda & Gray, 2007), dart throwing (Lohse, Sherwood, & Healy, 2010; Marchant, Clough, & Crawshaw, 2007), bimanual coordination (Hodges & Franks, 2000), accurate force production (Lohse, 2012; Lohse, Sherwood, & Healy, 2011), agility (Porter, Nolan, Ostrowski, & Wulf, 2010), vertical jumping (Wulf & Dufek, 2009; Wulf, Dufek, Lozano, & Pettigrew, 2010), and standing long jump (Porter, Ostrowski, Nolan, & Wu, 2010; Wu, Porter, & Brown, 2012) as well as others.

The effects these different attentional foci have on motor learning and performance have been explained by the constrained action hypothesis (Wulf et al., 2001; Wulf, Shea, & Park, 2001). According to this hypothesis, an EF facilitates the automatic self-organization of movement whereas an IF produces conscious interference of those otherwise automatic control processes. Automaticity is associated with greater economy in movement production and motor unit recruitment, as revealed by reduced neuromuscular activity and different mean power frequency profiles when utilizing an EF compared to IF (Vance, Wulf, Tollner, McNevin, & Mercer, 2004).

Reaction time is a measure of the time from the arrival of a stimulus to the beginning of the response to it. This measure can become longer or shorter depending on the number of stimuli that could be presented, or the number of choices that can be made depending on those stimuli. The fewer the number of stimuli and the number of possible associated responses, the shorter the RT. According to Jensen (2011), simple reaction time (SRT) latencies provide one of the most objective metrics for comparing processing speed. During a SRT task, there is only one appropriate response to a known stimulus and, as such, the shortest RTs occur during this type of task. For example, during a track sprint start, leaving the blocks as fast as possible is the only appropriate desired response to the firing of a starting gun. Shorter RTs have been shown under an EF, compared to an IF, during a track sprint start (Ille et al., 2013).

Even though RT has been shown to be influenced by attentional foci, it is uncertain whether these changes occur during the stages of central processing of information, or through peripheral mechanisms during the conduction of the electrical impulse and/or during the contraction of the muscles.

The central and peripheral events that occur during a RT task can be partitioned into premotor and motor RT within the RT paradigm. Premotor RT is the interval from the arrival of the stimulus to the first change in electromyography (EMG), and motor RT, the interval from the first change in EMG to the detection of force. Premotor RT is associated with the stages of information processing which includes stimulus detection, response selection and response programing, while motor RT is associated with the excitation contraction coupling of the muscle fibers (Schmidt & Lee, 2011). Although there is conflicting evidence of selective recruitment or reversal of size principle during ballistic movement (MacDougall & Sale, 2014), maximum shortening velocity of the muscle is determined by the fastest fibers (Josephson & Edman, 1988). Therefore, during movement that requires maximum power production, the active fibers should be the same resulting in the same speed of excitation contraction coupling if the movement were repeated without fatigue.

By distinguishing premotor and motor RTs within an SRT task, it is possible to assume that any changes observed within premotor RT, with no change in motor RT, are occurring due to changes in central processing speed. Furthermore, by using an SRT task in which the stimulus is known, and there is only one appropriate response, any changes in premotor RT are likely occurring within the response programing stage of information processing.

The purpose of the present study was to determine whether instructions promoting external versus internal focus of attention would influence RT during a track sprint start SRT task. An additional primary interest was to determine if focus of attention manipulation would influence primarily central processes during movement preparation, or peripheral processes during movement execution. We hypothesized that RT would be shorter under EF as compared with IF. More importantly however, we would expect that if attentional focus influences primarily central processing, the premotor RT would be longer under IF compared to an EF condition, with no differences in motor RT or in the time required for the muscle to produce peak levels of force.

These findings have the potential to contribute to a better understanding of the constrained action hypothesis by distinguishing if the reduction in RT under an EF occurs within central processing of information, or through peripheral mechanisms.

METHODS

Participants

Twelve Division III collegiate track sprinters (18 to 25 years old) volunteered to participate in the study (n=8 women, n=4 men). Participants were familiar with the task, but naïve to the purpose of the study. Informed consent was obtained from participants before testing began. All forms and experimental methods were approved by the University of Wisconsin – La Crosse Institutional Review Board.

Apparatus

Sprints were conducted on a synthetic indoor track surface. Force data were acquired for the front and rear foot via two force plate sensors (FP3, Biometrics Ltd., Newport, UK) mounted to a standard track starting block. Electromyographic data were acquired through a Delsys Trigno™ (Natick, MA) wireless system from the left and right vastus lateralis (VL), as well as the left and right medial gastrocnemius (GM). These muscles have previously been identified as prime movers during a track sprint start (Coh, Peharec, Bacic, & Kampmiller, 2009). The force and EMG data were time synchronized through an A/D board (USB-6210, National Instruments, Austin, TX), sampled at 2000 Hz, and stored on a personal computer (Latitude E6530, Dell, Round Rock, TX) for further analysis. The start signal was produced by a gunshot sound clip (44,100 Hz; 16 bits/sample), and played through external speakers (Labtec LCS-1030, Logitech, Newark, CA) placed behind the starting block. Data acquisition and processing was performed through a custom program (Matlab, Mathworks, Natick, MA).

Procedure

Three separate sessions were used to collect data under three different focus conditions: no focus (NF), external focus (EF) and internal focus (IF). No additional instructions were given during the NF condition. Participants were instructed to “focus on pushing the blocks away” during the EF condition, and during the IF to “focus on extending your knees”. Test sessions were separated by a minimum of two days. Fifteen starts were performed each session, with ~1-2 minutes of rest between each trial. Participants performed their routine warm-up before each test session as they would before a competitive sprint event. They were instructed to accelerate as fast as possible to a line placed 6 meters from the start line. This distance was chosen in order to give the athletes a distance goal, while also minimizing fatigue that could occur from running longer distances. Before the trials, participants were informed that they would receive the start commands “on your mark” and “set” before hearing the gunshot. The focus cues were given following the “on your mark” command, but before the “set” command and gunshot. The first session always consisted of the NF condition, while the EF and IF conditions were completed utilizing a counterbalanced within-subject design.

Signal Processing

Data was collected and analyzed using custom developed computer programs (Matlab). The force signal was filtered using a second order low-pass Butterworth filter with the cut-off frequency set at 15 Hz, and with zero phase-shift. Similarly, to obtain the linear envelope, the rectified EMG signal was filtered with a cut-off frequency of 35 Hz.

Premotor RT was determined as the time elapsed between the auditory signal and the detection of a 5% change relative to maximum in the EMG envelope. Motor RT was determined as the time elapsed between the occurrence of a 5% change relative to maximum in the EMG envelope and a 5% change from the maximum force applied against the block. The time elapsed between the auditory signal and the detection of a 5% change from the maximum force applied against the block was determined as the RT (Figure 1).

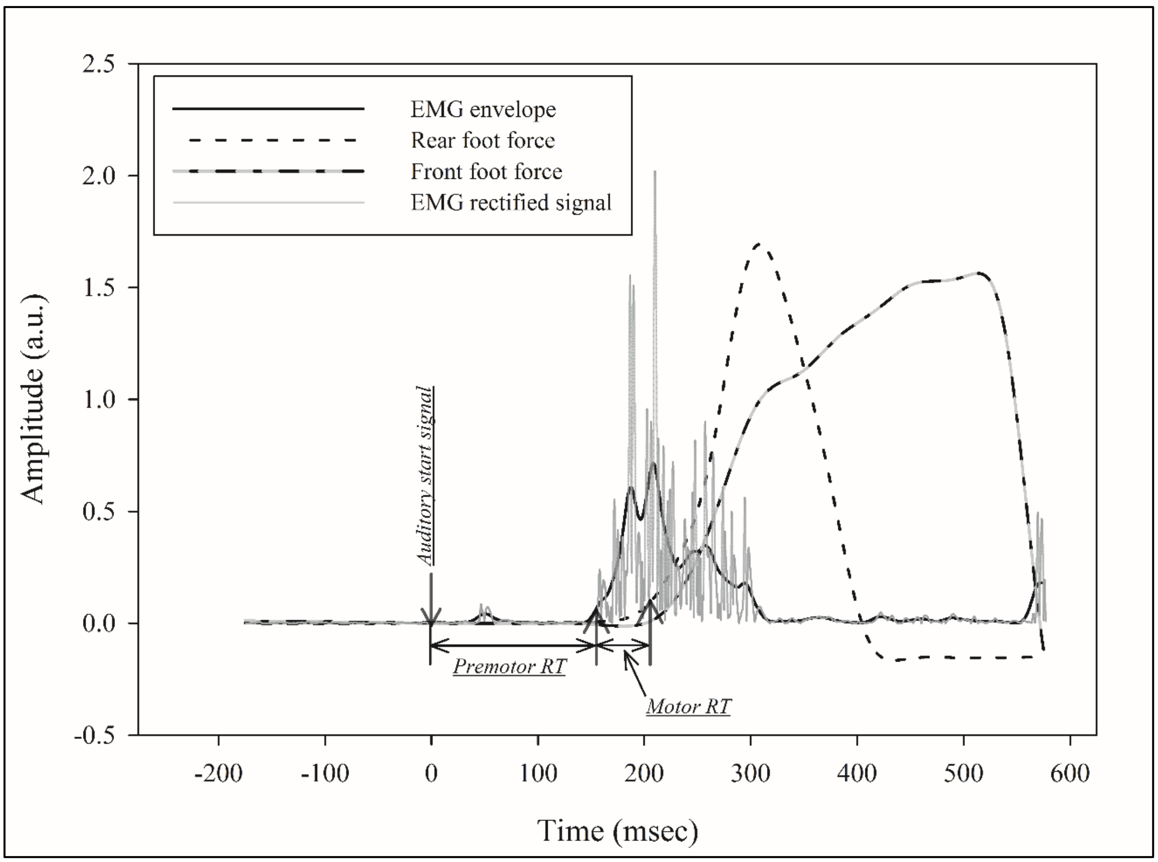

Figure 1. Example of force and rectified EMG signals of the vastus lateralis after filtering. Onset was determined as a 5% change in signal amplitude relative to the maximum value of each signal.

Statistical Analysis

Standard deviation around the mean assumes normal distribution, making it strongly impacted by outliers and unlikely to detect outliers in small samples. Unlike standard deviation around the mean, absolute deviation around the median is insensitive to the presence of outliers, and immune to sample size (Leys, Leys, Klein, Bernard, & Licata, 2013). Therefore, in order to detect and eliminate outliers before further analysis, absolute deviation around the median was used.

A preliminary analysis, separating the total trials within each focus condition into three groups (trials 1-5, 6-10, and 11-15), was used to detect any potential changes in RT due to fatigue over the course of fifteen trials. A one-way ANOVA with repeated measures on groups failed to detect any differences, indicating no fatigue occurred over the course of the testing. Therefore, all fifteen trials were grouped together for further analyses.

Timing variables were averaged across fifteen repetitions within one testing session and analyzed using a one-way ANOVA with repeated measures on focus factor. The ANOVA was performed for each dependent variable. Post hoc tests were completed using the Bonferroni correction. Criterion for significance level was set using an alpha level ($p<0.05$). Data are presented as means and standard error of the means (SE) in the text, figures and table.

RESULTS

Reaction time

Rear foot RT was determined to be significantly different between focus conditions ($F_{(2,22)}$=14.996, $p<0.05$). The effect size (β^2=0.997) indicated a large magnitude of observed differences. Post hoc tests revealed that rear foot RT during the EF condition (M=212.11, SE=8.45 ms) was significantly shorter than both IF (M=234.21, SE=5.76 ms) and NF conditions (M=236.87, SE=8.82 ms) ($p<0.05$), with the last two not being different from one another ($p>0.05$) (Figure 2).

Front foot RT was also found to be significantly different between focus conditions ($F_{(2,22)}$=4.541, $p<0.05$). Post hoc tests revealed that front foot RT during the EF condition (M=250.24, SE=17.24 ms) was significantly shorter than IF (M=266.98, SE=16.44 ms) but not NF (M=268.73, SE=14.23 ms) ($p<0.05$). No difference in front foot RT was found between IF and NF conditions ($p>0.05$) (Figure 2).

Time to peak force

No significant difference was found between EF, IF, and NF in rear foot time to peak force (M=190.80, SE=15.81 ms; M=211.79, SE=21.50 ms; M=195.09, SE=17.24 ms; respectively), or front foot time to peak force (M=359.89, SE=8.28 ms; M=348.55, SE=16.87 ms; M=340.96, SE=17.54 ms; respectively) (Figure 3).

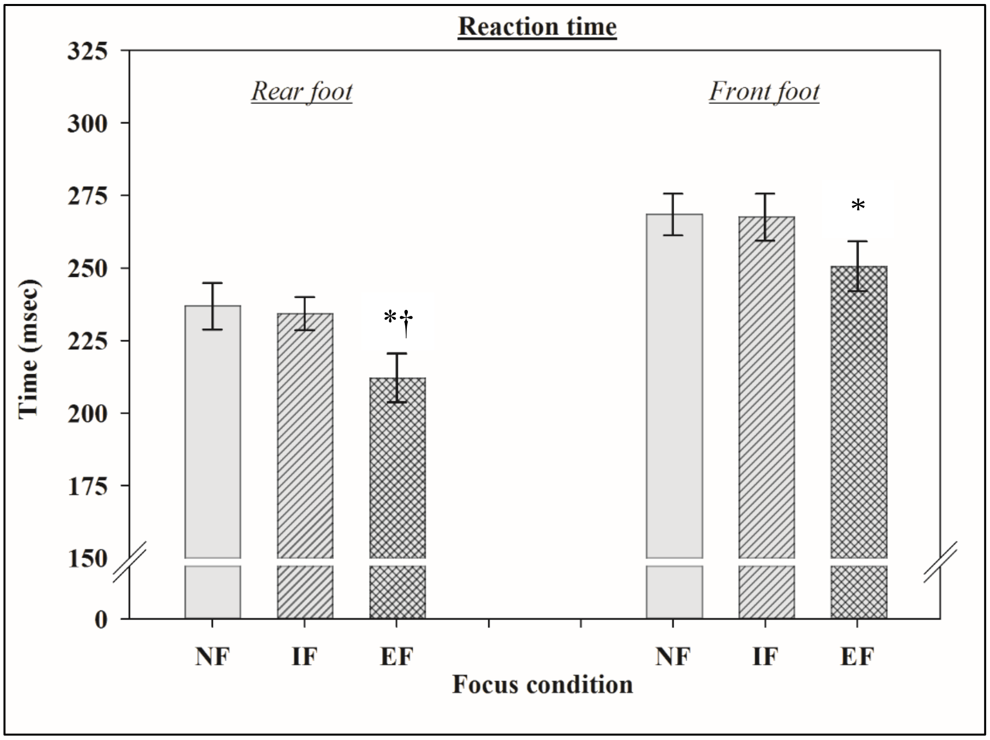

Figure 2. Reaction time recorded at the force plates across focus conditions.
* Significantly less than IF (p<0.05).
† Significantly less than NF (p<0.05).

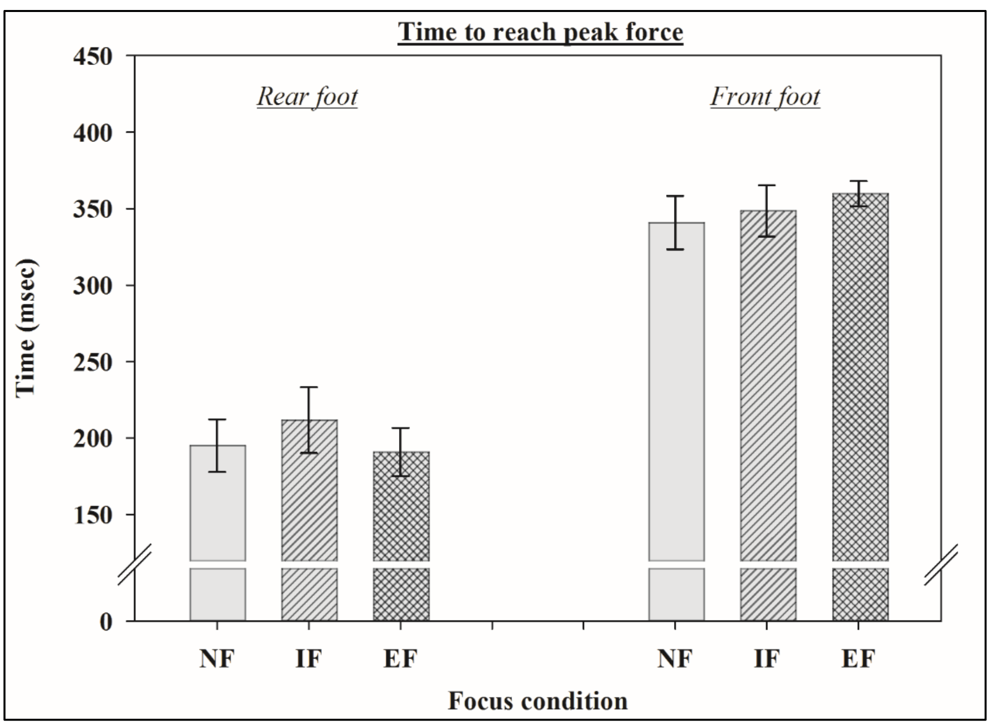

Figure 3. Time to peak force across focus conditions.

Electromyography

Because the rear foot VL was the first muscle activated during the sprint start task, premotor RT was determined as the time elapsed between the gunshot and the activation of the rear foot VL. Motor RT was determined as the time interval between rear foot VL activation and the initiation of force production.

Rear foot VL activation was significantly different between focus conditions ($F_{(2,22)}=10.541$, $p<0.05$). The effect size ($\beta^2=0.976$) indicated a large magnitude of observed differences. Post hoc tests revealed that activation of the rear foot VL during EF (M=157.75, SE=7.38 ms) occurred significantly earlier than IF (M=181.90, SE=5.72 ms) but not significantly earlier than NF (M=173.60, SE=7.30 ms) (Figure 4). No difference in front foot RT was found between IF and NF conditions ($p>0.05$).

Front foot VL EMG activation was also determined to be significantly different between focus conditions ($F_{(2,22)}=9.228$, $p<0.05$). The effect size ($\beta^2=0.957$) indicated a large magnitude of observed differences. Post hoc tests revealed that activation of the front foot VL during EF (M=174.90, SE=8.42 ms) occurred significantly earlier then IF (M=195.98, SE=6.93 ms), and NF (M=213.42, SE=11.43 ms) (Figure 4). No difference in front foot RT was found between IF and NF conditions ($p>0.05$).

No significant difference was found in time from rear foot VL activation to rear foot force initiation between EF (M=60.67, SE=6.61 ms), IF (M=58.04, SE=2.82 ms), and NF (M=61.61, SE=6.57 ms) conditions. Additionally, no difference was found in time from front foot VL activation to front foot force initiation between EF (M=61.50, SE=4.06 ms), IF (M=57.30, SE=4.50 ms), and NF (M=61.03, SE=7.60 ms) conditions.

No significant difference in rear foot GM activation was found between EF (M=240.90, SE=15.68), IF (M=260.40, SE=14.02), and NF (M=249.21, SE=12.06) conditions. Front foot GM activation was not significantly different either between EF (M=282.85, SE=25.31), IF (M=286.58, SE=20.69), and NF (M=289.77, SE=18.10).

A summary of the results can be found in Table 1.

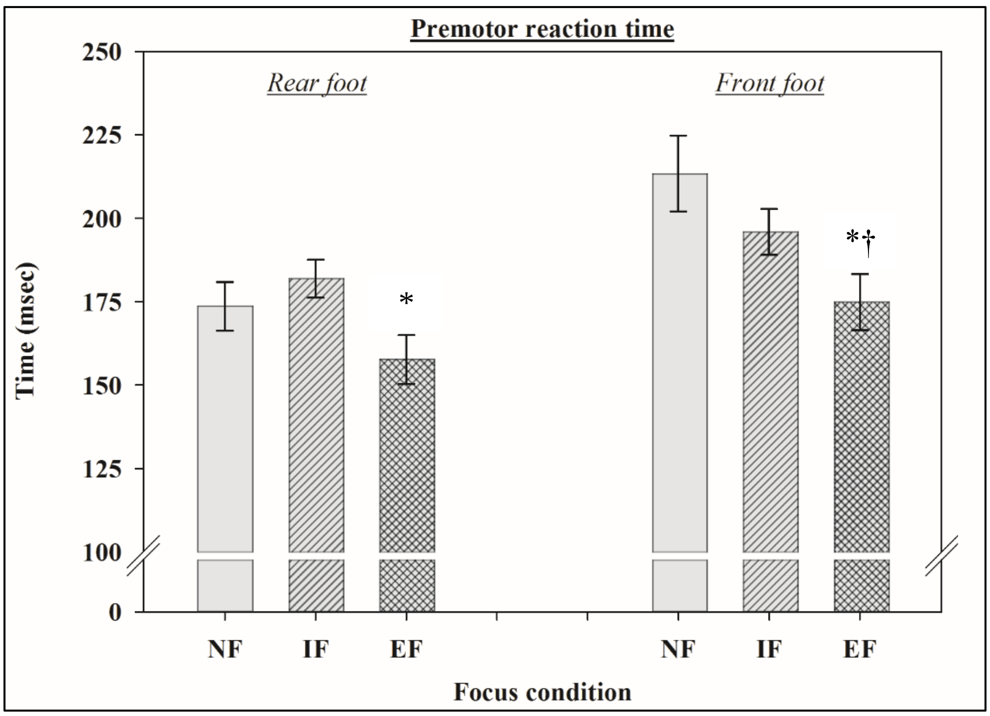

Figure 4. EMG activation time for vastus lateralis (premotor RT) across focus conditions.
* Significantly less than IF (p<0.05).
† Significantly less than NF (p<0.05).

Table 1. Mean time (ms) for each attentional focus condition (SE in parentheses).

	EF	IF	NF
Rear foot			
Premotor RT (VL EMG)	157.75 (7.38)*	181.90 (5.72)	173.60 (7.30)
Motor RT	60.67 (6.61)	58.04 (2.82)	61.61 (6.57)
RT	212.11 (8.45)* †	234.21 (5.76)	236.87 (8.82)
Time to peak force	190.80 (15.81)	211.79 (21.50)	195.09 (17.24)
GM EMG	240.90 (15.68)	260.40 (14.02)	249.21 (12.06)
Front foot			
Premotor RT (VL EMG)	174.90 (8.42)* †	195.98 (6.93)	213.42 (11.43)
Motor RT	61.50 (4.06)	57.30 (4.50)	61.03 (7.60)
RT	250.24 (17.24)*	266.98 (16.44)	268.73 (14.23)
Time to peak force	359.89 (8.28)	348.55 (16.87)	340.96 (17.54)
GM EMG	282.85 (25.31)	286.58 (20.69)	289.77 (18.10)

* Significantly less than IF (p<0.05).
† Significantly less than NF (p<0.05).

DISCUSSION

The purpose of the present study was to determine whether instructions promoting external versus internal focus of attention would influence RT during a track sprint start SRT task. An additional primary interest was to determine if focus of attention manipulation would influence primarily central processes during movement preparation, or peripheral processes during movement execution. Reaction time was observed to be significantly shorter under an EF compared to the other focus conditions. More importantly however, premotor RT was significantly shorter under an EF condition compared to both IF and NF with no changes in motor RT, or the time for the muscle to produce peak levels of force observed between the focus conditions.

According to the constrained action hypothesis, focusing internally hinders performance through conscious interference of a movement, while an EF on the other hand would allow the motor system to program a more automatic response. If this interference occurs within the central processing stages rather than through peripheral mechanisms, the result should be a prolonged premotor RT under the IF condition, and no difference in motor RT. Conversely, if the interference occurs primarily at the level of peripheral mechanisms, the result would be a prolonged motor RT and no difference in premotor RT. The results of this study support previous research (Ille et al., 2013) indicating a beneficial effect of EF, compared with IF, on RT, with the athletes exhibiting a shorter RT under the EF condition. More importantly however, these results provide evidence suggesting that the shorter RT under the EF condition is due to a faster movement preparation process rather than improved automaticity of the peripheral mechanisms.

In a RT task, pre-movement time is thought of as the time required to execute a whole set of processes associated with movement planning, and in general does not dissociate between these processes. Due to the stimulus and response associated with it being known in the current study, the observed shortening of the RT under the EF condition might be due to a more efficient response programming stage. The attenuation of muscle activation time, as assessed by EMG, indicates that under the EF condition the motor commands reached the muscle earlier as opposed to the IF or NF condition. With no difference observed between the focus conditions in the time between muscle activation and force initiation, or motor RT, the attenuation in RT can be explained by a faster premotor RT. Because changes were only observed within the premotor RT and not the motor RT, the observed increase in RT under the IF condition were likely due to additional time taken for central processing.

Additionally, motor RT was similar under the different focus conditions, suggesting that propagation of the nervous impulse and the initial excitation-contraction coupling at the muscle level was not influenced by the type of focus adopted. Moreover, the rate of force production, as illustrated by the time to peak force, was similar under the different focus conditions indicating that the muscles were contracting at the same velocity regardless which type of attentional focus was adopted.

These results indicate that all peripheral mechanisms related to the contraction of the muscles, occurred similarly across the different conditions, further suggesting that any improvements in RT under the EF condition were due to a shortening of the time required for the central processes. This raises the question of what might these specific central processes be? Using electrophysiological measures, Lohse et al., 2011 and Wulf et al., 2010, suggest that the way motor units are recruited under IF relative to EF is less efficient due to increased co-contraction between agonist and antagonist muscle pairs. In the present experiment, the electrophysiological activity of the antagonist muscles was not recorded. However, it is possible that the observed increase in the time needed to initiate muscle activation (premotor RT) under the IF condition, was due to the additional processing of parameters needed to control the activity of the antagonist muscles.

Practical applications

Porter, Wu, and Partridge (2010) determined that 84.6% of track and field coaches use cues that instruct athletes to focus internally and that 69.2% of the athletes utilize internal focus during competition. With no additional instructions given, the athletes in the current study likely self-selected to focus internally during the NF condition. This possibly explains why longer and similar premotor times were observed under the NF as well as the IF condition compared to the EF condition. By utilizing EF cues, track and field coaches may be able to further enhance their athletes sprint performance. This effect may be even more important for developing sprinters. In addition to external focus being effective with motor learning, use of external cues early on in an athlete's development may promote self-selecting external focus when the athletes are unable to receive cues from a coach.

Previous studies using tasks whereby efficiency relies on the capability to produce high levels of power such as standing long jump (Porter et al., 2010) or vertical jump (Wulf & Dufek, 2009; Wulf et al., 2010), have shown that adopting an EF, as opposed to an IF, improves performance. Although in the present study the absolute amount of force produced under the different focus conditions was not assessed, it would be interesting to see in the future whether a faster RT under an EF condition would also translate into an increased level of force produced. If that is the case, and given that the present study shows that time to peak force was quite similar under the various focus conditions, this would suggest that the amount of power produced by the athletes would also be different.

Conclusions

Taken together, the pattern of results from this experiment provides additional evidence that an EF is better than IF for motor performance, during a discrete task. This is the first study that provides electrophysiological evidence that suggests that EF does indeed reduce movement preparation time.

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APPENDIX A

INFORMED CONSENT

Informed Consent
Attentional Focus and Reaction Time during track start.

I, _________________________________, volunteer to participate in a research study being conducted at the University of Wisconsin - La Crosse.

Purpose and Procedure:
- The purpose of this study is to investigate reaction time and muscle activity (as measured by EMG) during a typical Track & Field start.
- My participation in this study will involve three sessions. Each session will last approximately one hour.
- The exercise to be tested will be a typical Track & Field start, out of the blocks.
- During each session I will perform a simple reaction time test first, where I will have to depress a pedal as quick as I can when an auditory signal is presented.
- Following this first test, I will perform 15 repetitions of a typical track start. This requires me to settle in the appropriate position, and upon the presentation of an auditory signal, start running as fast as I can for a short distance (approximately 20 meters).
- During all sessions I will have adhesive electrodes placed on my leg muscles in order to record muscle activity.
- Research assistants will be conducting the research under the direction of Dr. Attila J. Kovacs, an Assistant Professor in the Department of Exercise Science.

Location: Field house indoor track in Mitchell Hall, and the UW-L stadium track.

Potential Risks/Discomforts:
- The risks in this experiment are minimal, but muscle fatigue and soreness may be experienced
- Minor skin irritation from placement of the EMG electrodes is possible
- The risk for serious or life-threatening complications, for healthy individuals like me, is near zero.

Potential Benefits:
- I, and other athletes, may benefit by gaining knowledge and in-depth analysis about our own technique used during a track start.

Rights & Confidentiality:
- My participation is voluntary
- I can withdraw from the study at any time, for any reason, without penalty of any kind.
- The results of this study may be published in the scientific literature or presented at professional meetings using group data only.
- All information will be kept confidential through the use of numeric codes
- My data will not be linked with personally identifiable information.

Compensation: No compensation will be given for this study.

I have read the information provided on this consent form. I have been informed of the purpose of the test, the procedures, and the expectations of myself as well as the testers, and the potential risks and benefits that may be associated with volunteering for this study. I have asked any and all questions that have concerned me and received clear answers so as to fully understand all aspects of the study.

Contact Information: In case of any problems or questions that may arise concerning the study, subjects may contact the primary investigator, Attila Kovacs. He can be reached by his office phone (608-785-8786), email (akovacs@uwlax.edu), or at his personal office in room 223A Cartwright. Questions regarding the protection of human subjects may be addressed to irb@uwlax.edu.

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Signature of Subject Date

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Signature of Investigator Date

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The purpose of this review of literature is to examine the effects of external focus of attention (EF) and internal focus of attention (IF) on information processing. Use of electromyography (EMG) as a method of measuring muscle activation, as well as track and field sprint start technique will be addressed as well.

Introduction

Optimization of performance is the focus of every athlete and coach. An ability to out-perform others is what leads to a successful result during competition. While becoming highly skilled in a movement takes a great deal of time and practice, both skilled and novice performers may benefit from changing their attentional focus. What performers focus on while executing a movement can have a substantial influence on the outcome.

Information Processing

Human information processing is typically based on a computer metaphor. Input from the environment is received via the sensory organs, undergoes processing, and then is utilized during output in the form of an action. Three stages of information processing occur between the presentation of a stimulus and the production of a response (Schmidt & Lee, 2011). First, the stimulus must be identified by the individual and is termed the stimulus identification stage. In this stage the occurrence of an environmental stimulus results in neurological impulses that are sent to the brain. The stimulus is processed at different levels until it contacts memory and some memorized aspect of the stimulus is aroused with which it has been associated in the past. Second, the individual must decide the appropriate response to the identified stimulus known as the response selection stage. Finally, the individual must prepare the appropriate muscle actions that will achieve the desired outcome. This is termed the response programming stage. This requires that a motor program of the action be retrieved from memory, prepared for activation, that relevant portions of the motor system be readied and that the movement be initiated. Information processing can be studied multiple ways but the most common is a chronometric approach which considers the duration of these various processes (Schmidt & Lee, 2011).

Reaction Time

Reaction time (RT) is a measure of the time from the arrival of a suddenly presented and unanticipated signal, to the beginning of the response to it (Schmidt & Lee, 2011). When only one appropriate response for a given stimulus is available, it is termed simple reaction time (SRT). When two or more stimulus-response (S-R) alternatives are available it is termed choice reaction time (CRT). As the number of S-R alternatives increases, the time required to respond increases due to an increased amount of information needing to be processed. The end result is an increase in RT during CRT, compared to SRT tasks.

This RT paradigm can be further broken down into smaller intervals based in relation to muscular activity during a RT task (Schmidt & Lee, 2011). After a warning signal, but before the stimulus is presented, there is a foreperiod. During this period, EMG is mostly quiet, meaning little muscle activation is detected. Following the stimulus presentation, there is an interval of time before a change in EMG is detected. The delay in muscle activation is due to the information being processed during this premotor RT stage. Before the muscles can be activated for a response, the stimulus must be identified, a response must be selected and then programmed to activate the appropriate muscles in order to achieve the desired movement. Once the motor program is selected, the activation pattern of the muscles needed to complete the movement are sent from the primary motor cortex down the motor neuron to the muscles in the form of electrical impulses. The time period elapsed between the first detected change in EMG of the muscle, until the detection of force output is termed motor RT, and represents the time needed for excitation contraction coupling of the muscle to occur. Therefore, RT is the sum of premotor RT and motor RT. Finally, from the detection of force or movement output, to the completion of the movement is designated as movement time (MT). Together, RT and MT make up the total response time.

External vs Internal Focus of Attention

An IF requires the performer to focus on their body's movements, while an EF requires an individual to focus their attention on the intended movement effect on an implement (Wulf, McNevin, & Shea, 2001). There has been increasing evidence over the years that adopting an EF enhances the automaticity of a movement indicated by a greater mean power frequency (MPF). Wulf et al. (2001) demonstrated this using a stabilometer under both conditions. The EF condition resulted in participants making more frequent and smaller amplitude adjustments (0.329 ± 0.011 MPF) relative to the IF condition (0.268 ± 0.011 MPF). Higher frequency responding has been characterized as indicating an effective integration and increase in the active degrees of freedom associated with performing a motor task and greater confluence between reflexive and voluntary control mechanisms (Wulf et al., 2001). Trying to consciously intervene in these control processes appears to result in a constraining of the degrees of freedom, less fluid interactions between control mechanisms, and less automatic movement execution (Wulf, McNevin, & Shea, 2001). This is the basis for the "constrained-action hypothesis" proposed by Wulf et al., (2001) which states that when performers utilize an IF to consciously control their movements, they may constrain or interfere with automatic control processes that would normally contribute to the regulation of the movement. By adopting an EF, a person allows the motor system to self-organize more naturally.

Efficiency

A movement pattern that is completed with the same outcome while using less energy is considered more efficient (Wulf, 2013). This is particularly important in competitions where fatigue can be a limiting factor.

An EF has been shown to reduce muscle activity while producing greater movement velocity during bicep curls (Vance, Wulf, Tollner, McNevin, & Mercer, 2004). The results from this experiment showed a reduction in electromyography (EMG) activity under the EF condition in not only the bicep (agonist), but also the triceps (antagonist). While an EF has been shown to produce greater force control with less muscular activity, there is also evidence that it may optimize maximal force production. Optimal activation of agonist and antagonist muscles, as well as optimal muscle fiber recruitment is required for maximal force production (Wulf, 2013). Marchant, Greig, and Scott (2009) had participants perform isokinetic maximum voluntary contractions (MVC) of the elbow flexors during a control condition and while focusing on either the crank bar

(EF) or their arm muscles (IF). The participants produced significantly greater peak joint torque during the EF condition, (101.10 ± 2.42% MVC), compared to the IF condition (95.33 ± 2.08% MVC). The results also showed lower peak EMG activity when focusing externally compared to internally, (134.43 ± 16.83% MVC; 155.23 ± 22.54% MVC) respectively.

Maximal jump height has also been found to be enhanced by adopting an EF (Wulf, Dufek, Lozano, & Pettigrew, 2010). While measuring EMG during a maximal jump height test using a Vertec, participants were instructed to concentrate on either the tips of their fingers (IF), or the rungs of the Vertec (EF). The results showed significantly greater jump height while focusing externally. Additionally, Wulf and Dufek (2009) measured the displacement of the center of mass (COM) during a maximal jump test. The results showed that in addition to achieving a greater height during the external compared to the internal focus condition, (31.9 ± 3.23 cm; 30.4 cm ± 3.04 cm) respectively, participants also had a greater displacement of their COM, during the external condition compared to internal condition (29.5 ± 1.5 cm; 26.2 ± 2.1 cm) respectively.

Endurance sports may also benefit from the greater efficiency demonstrated from using an EF. These longer-duration tasks, where fatigue is a limiting factor, may benefit from the enhanced movement automaticity and efficiency associated with an EF (Wulf, 2013). Marchant, Greig, Bullough, and Hitchens (2011) measured the number of repetitions to failure at 75% 1-RM during bench press and back squat on a Smith Machine. Participants were instructed to focus on either the bar being moved (EF) or their limbs involved (IF) while performing the repetitions. An EF resulted in significantly greater repetitions to failure for the bench press and back squat (10.82 ± 0.2; 11.06 ±

0.18), compared to IF (9.58 ± 0.21; 10.06 ± 0.18) and the control focus condition (9.53 ± 0.30; 9.77 ± 0.20) respectively.

More evidence of how changing the focus of attention can affect endurance performance can be seen from studying running economy. Schucker, Hagemann, Stauss, and Volker (2009) had skilled runners focus internally on a movement-relevant aspect of the task (running form), internally on a movement-irrelevant aspect of the task (breathing), or externally on a video that displayed a simulation of running outdoors. The results showed a reduction in oxygen consumption during the EF condition, (39.1 ± 4.38 ml/kg-1/min-1), compared to the movement-relevant and movement-irrelevant conditions, (40.68 ± 4.64 ml/kg-1/min-1; 42.8 ± 5.15 ml/kg-1/min-1) respectively. This indicates an increase in running economy when focusing externally.

Effectiveness

A movement that can be performed consistently, reliably, and with greater accuracy is considered to be effective (Wulf, 2013). Lohse, Sherwood, and Healy (2011) examined if an EF or IF affected a subject’s ability to produce a specific amount of force. Participants were instructed to perform an isometric contraction by pressing against a force platform with their dominant foot at 30% of their MVC. Electromyography measurements were taken from the soleus (agonist) and the tibialis anterior (antagonist). Participants were instructed to focus on either their calf muscles (IF) or the force platform (EF). An EF resulted in less absolute error in force production (9.11 ± 1.38 N) compared to an IF (10.01 ± 1.69 N). Additionally, there was a greater amount muscular activity in the antagonist muscle during the IF condition (19.0 ± 1.3% MVC) compared to the EF condition (6.9 ± 1.1% MVC). This demonstrates that an EF, compared to an IF, is not only more effective at producing a more accurate force, but also more efficient indicated by reduced muscular activity.

Focus of attention has also been shown to have an effect on golf shot accuracy. Wulf and Su (2007) used both novice and expert golfers to test the effect of EF and IF on golf shot accuracy. While an IF showed no change in accuracy, both the novice and expert golfers had an increase in accuracy while focusing externally. It is important to point out that this study demonstrates that even expert performers can benefit from adopting an EF.

Further evidence supporting the beneficial effect of an EF has on accuracy has been assessed with dart throwing (Lohse, Sherwood, & Healy, 2010). Subjects produced less error and had less EMG activity in the triceps while focusing externally, compared to internally.

Quality of Instruction

It is important to note that while changing a person's focus of attention may influence the movement outcome, the quality of the instructions given may also impact performance. Poor quality of instruction has been demonstrated to have a negative impact on performance regardless of the direction of focus (Polsgrove, Parry, & Brown, 2016). Polsgrove et al. (2016) had five conditions under which subjects performed an agility "L" run. The conditions included a control, external focus performance neutral (EF-PN), external focus performance enhancing (EF-PE), internal focus performance neutral (IF-PN) and internal focus performance enhancing (IF-PE). The only instructions for the control condition were to "run through the course as quickly as you can with maximum effort". The EF-PE instructions were to "focus on running towards each cone as fast as possible while pushing off the ground as powerfully as possible throughout the course". EF-PN instructions were to "Focus on running the shortest path while minimizing air resistance throughout the course". IF-PE instructions "Focus on contracting your leg muscles as forcefully and rapidly as possible throughout the course". Finally, the IF-PN instructions were to "Focus on keeping your head as relaxed as possible throughout the course". Both performance neutral focus conditions resulted in slower times compared to the performance enhancing conditions. This demonstrates that the quality of instruction plays an important role in directing focus. Explicit directions, using clear and concise language should be utilized when directing a performer's attention.

Electromyography

"Electromyography is the study of muscle function through the inquiry of the electrical signal the muscles emanate" (Basmajian & De Luca, 1985). "The EMG signal is the electrical manifestation of the neuromuscular activation associated with a contracting muscle" (Basmajian & De Luca, 1985). It provided investigators with the means to measure the activation timing of muscles, the force/EMG signal relationship, and use the EMG signal as a fatigue index (De Luca, 1997).

In order to appreciate EMG, one must have an understanding of structural and functional units of striated muscle. Because the plasma membranes of muscle fibers and neurons exhibit voltage changes in response to stimulation, they are considered electrically excitable cells. In striated muscle, the structural unit of contraction is the muscle cell, also referred to as a muscle fiber. The fibers likely never contract individually under normal conditions in mammalian skeletal muscles (Basmajian & De Luca, 1985). Instead, they contract as part of a group. Each group of muscle fibers are innervated by the terminal branches of a single motor neuron. While motor neurons innervate multiple muscle fibers, muscle fibers are only innervated by one motor neuron. Together, the single motor neuron, its terminal branches, and all the muscle fibers it innervates form a motor unit. An electrical impulse descending the motor neuron causes all the muscle fibers it innervates to contract simultaneously. Thus, the functional unit of striated muscle is the motor unit.

In an unstimulated neuron or muscle cell, there are more negative ions on the inside of the plasma membrane than on the outside. This makes the plasma membrane electrically polarized compared to the outside of the cell. When the cells are stimulated, ion gates in the plasma membrane open allowing cations (positively charged ions) to flow into the cell. This briefly changes the inside of the membrane to become positive and is called depolarization. In order to repolarize, the cell must open different ion gates that let cations out of the cell. This quick voltage shift, from negative to positive and back, is known as an action potential (AP).

As an impulse propagates down a neuron and reaches the neuromuscular junction, the electrical impulse is transferred from the neuron to the muscle. The depolarization of the postsynaptic muscle fiber membrane propagates in both directions along the fiber. This membrane depolarization is accompanied by a movement of ions which generates an electromagnetic field in the vicinity of the muscle fibers. With respect to ground, an electrode placed in this field will detect the potential or voltage. The time excursion of this voltage is the AP. “The individual muscle fiber action potentials represent the contribution that each active muscle fiber makes to the signal detected at the electrode site” (Basmajian & De Luca, 1985). The EMG signal can be affected by the anatomical and physiological properties of muscles, the control scheme of the peripheral nervous system, as well as the characteristics of the instrumentation that is used to detect it (Basmajian & De Luca, 1985).

Electrodes

Electrodes are used in EMG to detect the electrical current generated by the ionic movement. While they come in different shapes and sizes, two main forms exist. Inserted, or wire and needle, electrodes are positioned within the muscle tissue. Surface, or skin, electrodes as the name suggests are situated on the skin, over the muscle of interest. This type of electrode will be the focus of this review.

Though surface electrode use has become increasingly common due to their non-invasive character, a primary limitation is that only surface muscles can be detected. Proper skin preparation is required when using surface electrodes to enhance the quality of an EMG measurement. Before applying the electrode, hair must be removed, the skin must be lightly abraded in order to remove dead epithelial cells, and alcohol used to remove any excess oils. Doing so lowers the electrical impedance, providing a higher quality signal for data collection.

Proper placement of an electrode is essential to detecting a quality signal. Electrodes should be placed using articulations and anatomical landmarks of the body. Although there is no singular method for placement of electrodes, some guidelines do exist (e.g. seniam.org). Additionally, they should be placed over the middle of the muscle belly, and parallel to the fibers. Improper placement could lead to erroneous signal detection due to great EMG variability.

Electrodes can have two different configurations. In a monopolar configuration, there is only one detection surface along with a reference electrode located in an environment which is electrically quiet. The drawback of this configuration is that the electrode will detect all electrical signals in the vicinity of the detection surface. This electrical noise includes signals radiating from power cords, outlets and other electrical devices.

This limitation can be overcome through a bipolar configuration. This configuration is comprised of two detection surfaces to identify two potentials in the muscle tissue with respect to a reference electrode. The two signals are then propelled to a differential amplifier which amplifies the difference of the two signals. This eliminates any common components in the two signals. Signals originating from the muscle of interest will be different at each detection surface due to the localized electrochemical events occurring in contracting muscle fibers (Basmajian & De Luca, 1985). The result is a higher quality signal with less noise.

Track and field sprint starts

The sprint start is best characterized as the period of time between the firing of the starting gun and the moment both feet have cleared the starting blocks. Starting blocks are mandatory for the 100 m dash and all other sprint races up to and including the 400 m dash according to governing track and field organization, the International Association of Athletics Federations (IAAF) (iaaf.org). The start of a short distance race is a crucial component that may impact total race time. Block clearance accounts for approximately 5% of the total 100 m race time (Harland & Steele, 1997). The sprinter must move from the stationary set position into an asymmetrical running action as fast as possible. In a sprint start RT is the time from the sound of the start gun to the first measurable change in force applied to the block after the gunshot. Movement time is from the end of RT to when the same foot has completed its first successful strike on the ground. Therefore, the response time in the sprint start is the time interval from the sound of the gunshot to the completion of the first foot strike (Majumdar & Robergs, 2011).

A fast sprint start technique is characterized by the sprinter providing a powerful thrust against the blocks with both feet and maximizing the horizontal component of force by keeping the angle of drive low (Harland & Steele, 1997). The greatest block velocities have been demonstrated with block angles of 40° for both feet (Mero, Kuitunen, Harland, Kyrolainen, & Komi, 2006). Skilled sprinters generally apply greater peak force on the rear block compared to the front block, with forces also being exerted more rapidly on the rear block (Harland & Steele, 1997). Because the front limb pushes twice as long as the rear limb, the front block impulse will tend to be larger despite greater average force output from the rear limb (Harland & Steele, 1997).

Conclusion

The benefits of an EF appear to be far reaching. Evidence consistently supports the outcome benefits provided from an EF. However, there is no empirical evidence so far as to where psychological changes occur between these two attentional foci. Because information processing is thought to take place within the premotor RT stage, differences in the length of time of this stage between the two conditions gives insight into the effect they have on information processing. During an SRT test, the stimulus is known by the individual, and there is only one appropriate response to be selected with regards to that stimulus. Thus, with stimulus identification and response selection controlled for, any changes observed within the premotor RT between the two conditions can be hypothesized to take place within the response programming stage of information processing.

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