

Running Head: GET ON THE GOOD FOOT

Get on the Good Foot:
Do Pedal Asymmetries Exist
in the Sprint Start Response?

A Thesis Presented to the
School of Kinesiology
Lakehead University

In Partial Fulfillment of
The Requirements for the Degree of
Masters of Science in Kinesiology

Adam Eikenberry

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Abstract

The study of pedal asymmetries examines the differences in reaction time and movement time between the foot/hemisphere systems in humans. Although asymmetries have been examined using pointing movements research has yet to be completed that examines pedal asymmetries in a functional movement such as the track and field sprint start. Using the track & field sprint start, 20 individuals (10 experienced, 10 inexperienced) were assessed for pedal asymmetries. Each participant performed 48 starts (24 right foot starts and 24 left foot starts). Variable foreperiods (1500, 2000, 2500 & 3000ms) were used to control for anticipations. A left foot (i.e., left foot in rear position) reaction time advantage was found. Right foot (i.e., right foot in rear position) advantages were found for movement time and response time. Foreperiod length did not affect reaction time. There were no significant differences between the experienced and inexperienced sprinters. The experience factor did not interact with any other factors. Preferred stance was evaluated as a control variable and did not affect the pattern of asymmetry. The pattern of pedal asymmetries in the sprint start response was consistent with that of manual asymmetries. Further, the results were consistent with a right hemisphere specialization for spatio-temporal processing, and a left hemisphere specialization for movement execution and on-line correction. The pattern of asymmetries extends to tasks using an auditory signal as an auditory tone was used to mimic the "starting gun".

Introduction

Every day, our environment presents us with the opportunity to process various stimuli. For example, a person driving a car may have to process that the traffic light has changed from red to green or a defender in soccer may have to process one out of a seemingly endless number of possible moves that an attacker may be able to execute. The speed in which we react is an important determinant of performance on a variety of tasks (e.g., driving a car, landing a plane, the sprint start). The speed in which we process the signal is not the only determinant of task performance. The ability to execute a movement quickly with a minimal amount of error is also important. As a result, efficient task performance must consider the speed of reacting to a signal (i.e., reaction time or RT) and the movement time (MT).

The choice of limb used to execute the task can affect the RT and MT for a given situation. The study of asymmetries examines the dissociation between the limb/hemisphere systems. In humans, each limb is controlled by the opposite hemisphere of the brain (Braun & Daigneault, 1994). Specifically, the right hemisphere controls the left hand and the left hemisphere controls the right hand¹. Due to the difference in hemispheric function, questions have arisen as to whether differences exist between these systems. The differences in

¹ 90% of left-handers have been shown to have the same hemispheric organization as right-handers, thus handedness has not been considered as a critical factor in examining asymmetrical effects (Herron, 1980). Similar patterns of asymmetry were found in both right and left-handers, suggesting that hand preferences were not the source of asymmetry (Boulinguez, Nougier and Velay, 2001; McAuliffe, Morden & Saj, 2002).

hemispheric function while using one's hands have been termed manual asymmetries. A right hemisphere advantage has been found for spatiotemporal processing and a left hemisphere advantage for movement production and on-line corrections (e.g., Boulinguez et al. 2000; Goodale, 1998). The other component of manual asymmetries is a right hand MT and movement accuracy advantage (e.g., Mieschke, Elliot, Helsen, Carson & Coull, 2001). The advantages found reinforce the concept of hemispheric lateralization.

Another potential factor affecting asymmetry is visual feedback. Buekers and Helsen (2000) examined the role of visual feedback in the right hand advantage. Their study used a manual aiming task. Participants performed the tasks with varying conditions between full and intermittent vision. One of their tasks was a rapid reciprocal tapping task. The right hand MT advantage was found, however, no interaction with the visual condition was present. The findings failed to support their hypothesis that the right hand system advantage was due to more proficient processing of visual feedback, as asymmetry did not increase when the visual feedback was degraded.

Lavrysen et al. (2003) examined the effects of practice on manual asymmetries using a manual aiming task. The one-target advantage hypothesis states that people initiate movements faster when there is one target rather than two. Their manual aiming task consisted of the presentation of a cue, followed by a delay, and then a response stimulus. In some trials, a second response stimulus was presented that participants were required to move to. Both right and left-handed participants were used in the study. During the initial set of

trials, they found a left hand RT advantage in both left and right-handers. A consistent one-target advantage was found regardless of hand used or hand-preference. However, prior to practice, the one target advantage was not present in left-handers. The results indicate that left-handers favor a more on-line mode of control than right-handers. After training, regardless of the hand that was trained, the one-target advantage was present. Their study failed to eliminate manual asymmetries through practice. If asymmetry is resilient to practice, some asymmetry should persist in highly practiced sport skills such as the sprint start.

Although the majority of the research on manual asymmetries has used visual stimuli, Chapman, Heath, Westwood and Roy (2001) found asymmetries using an auditory signal. Asymmetry effects have been found with an auditory start signal and the following responses: kinesthetic guidance to the target (Chapman, et al., 2001), visual location of the target (Buekers & Helsen, 2000), or target location with the absence of vision (Carnahan & Elliott, 1987). Recently, Neely, Binstead & Heath (2005) used an auditory start signal in a bimanual reaching paradigm. They found a left hand RT advantage, but failed to produce the expected right hand MT advantage. When using an auditory starting stimulus the RT effects are similar to those with visual cues, but the MT effects are equivocal.

While manual asymmetries have been the subject of much research, little has been done to examine whether the asymmetries exist when using the feet. One study that examined pedal asymmetries was conducted by Carnahan

and Elliot (1987). Participants aimed and pointed to targets with their feet in response to an auditory cue. A left foot RT advantage was found, similar to that in the left hand (e.g., Mieschke et al., 2001), suggesting that asymmetries extend to tasks that involve movement of the feet.

One sport specific task that is performed with the feet is the track & field sprint start. Sprint races have long been the marquee events in track & field. The modern sprint races include 100m, 200m and 400m events, in addition block starts are also used for the 110m (100m for women) and 400m hurdle races. Due to the short duration of the sprint events, every thousandth of a second is important. In a 100m race, the start (i.e., from the sound of the “starting gun” until both feet have cleared the starting blocks) can account for approximately 5% of the total race time (Harland & Steele, 1997).

The sprint start differs from distance races in that the athlete uses specifically designed starting blocks. The starting blocks have evolved over the years, but generally consist of a metal spine, with two adjustable pedals that attach to it. The starting blocks are set-up in a comfortable position, so that the sprinter, while using them, can keep their hands behind the starting line. The starting blocks are generally set-up in a staggered manner, so that one leg is positioned in front of the other. There is no consistent school of thought to determine which leg should be in the forward or rearward position. The decision is based on the sprinter’s determination of comfort. That is, to date, the decision of whether or not a sprinter is a right foot or left foot starter is one of preference.

The timing of the front and rear leg action in the sprint start differ. Rear leg RTs have been found to be faster than front leg RTs, despite faster pre-motor activities in muscles of the front leg (Henry, 1952; Mero & Komi, 1990). As there are both right and left foot block configurations, pedal asymmetries may exist in the sprint start response. While the action of each leg has been examined in the sprint start, none of the examinations looked for asymmetries between block configurations. For the purpose of the present investigation, a right foot starter will be a sprinter who prefers their right leg in the rear position, and a left foot starter one that prefers their left in the rear.

The sprint start response can be broken down into two components, reaction time (RT) and movement time (MT). The response time refers to the duration of the sprint start response. The response time can be quantified as the time from the stimulus presentation (gun) until the instant where the sprinter has exited the starting blocks (or the summation of both RT and MT). While the impact of the response may continue for a portion of the race, the response itself is delimited to this finite period in time.

Reaction time (RT) is defined as the time from stimulus onset until the first sign of overt movement. In the sprint start, the first sign of overt movement could be quantified as the first change in force. Small preparatory movements may occur prior to the first overt movement. Reaction time reflects the time needed to process a signal, select a response and program the response (see Figure 1). When a stimulus is presented, the initial step in processing the signal is to determine when the signal is turned on, and what it is. Following stimulus

identification, the appropriate response must be selected. Once selected, the correct response program must be implemented for the output to occur (Schmidt & Wrisberg, 1998).

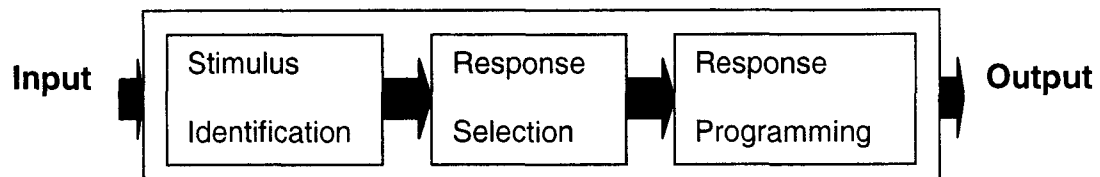


Figure 1. Model of Information Processing.

In a simple reaction time (SRT) there is one stimulus and one possible response (Henderson & Dittrich, 1998). The only uncertainty in an SRT is temporal uncertainty. That is, the person does not know when the imperative stimulus will be presented. The SRT situation provides for quicker responses as the stimulus simply has to be detected and the response executed. With only one possible response, the program can be pre-selected. For example, in a sprint race, once the “set” command has been given and the starting pistol has been fired, the only possible response is to leave the starting blocks.

One factor that has a significant effect on SRT is the length of time between the warning signal and the imperative stimulus; the foreperiod. For example, in a sprint race, the delay between the “set” command and the starting gun would be the foreperiod (see figure 2). When foreperiods are constant, the stimulus can be easily anticipated and SRTs are much quicker (Requin, 1985). With a constant foreperiod it is difficult to determine if the SRT values truly reflect

information processing time because of anticipations. It is possible that the participant has completed the processing operations *a priori* and has engaged in a time keeping task. In other words, the participant is anticipating the stimulus instead of reacting to the stimulus. As a result, the truncated SRTs under constant foreperiods conditions may not necessarily reflect true SRTs.

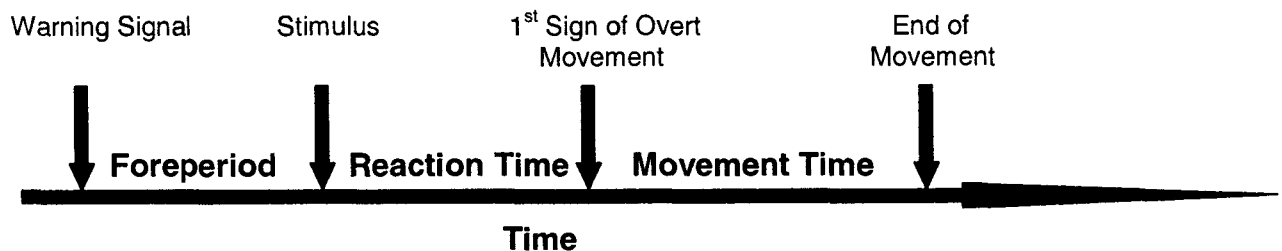


Figure 2. Time Course of Events in a Simple Reaction Time

To prevent anticipation, researchers often vary the foreperiods. Variable foreperiods create temporal uncertainty as to the presentation of the imperative stimulus (Niemi & Naatanen, 1981). In variable foreperiod situation, one factor that can affect RT has been termed the “aging” foreperiod (Naatanen & Merisalo, 1977). When there are a limited number of equiprobable variable foreperiods (e.g., foreperiods of one, two, three and four seconds), as time continues between presentation of the warning signal and the starting stimulus, reaction time becomes quicker. The momentary probability of the response stimulus being presented increases as the foreperiod continues. For example, if there are four possible foreperiods (1, 2, 3 and 4, seconds) then initially there is a .25 chance of the stimuli occurring at the first foreperiod duration. After one second has elapsed the momentary probability is .33 that the stimuli will occur at one of

the remaining three foreperiod durations. After two seconds has elapsed the probability that the stimuli will occur at either of one of the two remaining durations is .50. After three seconds the participant could be anticipating, as the probability is 1.00 that the stimulus will occur at four seconds. Conversely, as foreperiod lingers onwards, the timekeeping ability of the participant decreases. As the delay becomes longer, the ability to discern one delay from another suffers. A decrease in relative time keeping ability makes it difficult to anticipate the starting stimulus (Niemi & Naatanen, 1981; Naatanen & Merisalo, 1977). Variable foreperiods are effective in preventing anticipation in an SRT paradigm, despite the aging foreperiod, they are a better way to achieve a true SRT than presenting a constant foreperiod model.

Another strategy to prevent anticipation is the use of catch trials. A catch trial is a trial where the warning signal occurs, but the imperative stimulus never comes. Traditionally, approximately 20% of trials in a block would be catch trials to discourage anticipation (McAuliffe, Pratt & O'Donnell, 2001). This method is inappropriate in a sprint start situation, as catch trials are not used in sprint races. Thus, in sprint races, a variable foreperiod method is used to control for anticipations. Following the "set" command, starters are instructed to vary the delay before they fire the starting gun. Further variation is included, as different individuals take different amounts of time to rise into the "set" position.

Efficient task performance is also reliant on Movement time. Movement time (MT) is defined as the time from the first sign of overt movement until the movement is complete (Schmidt & Wrisberg, 1998). For example, in the sprint

start, the MT would be the time from movement initiation (end of RT) until the instant where the sprinter is no longer in contact with the starting blocks (Sanderson, McClements & Ganders, 1991). Movement time is primarily a function of the musculature involved and the task complexity. As task complexity increases, so does movement time (Niemi & Naatanen, 1981). The total response time is the summation of the reaction and movement times, giving you the time from stimulus presentation until the end of the movement.

Mero and Komi (1990) measured RT in sprint starts using electromyography (EMG) readings from a variety of locations on the lead and trail legs. Rear leg gluteus maximus, and front leg gastrocnemius were the first responding muscles. Rear Leg RTs were found to be faster than front leg RTs, despite faster pre-motor activities in some muscles of the front leg. EMG is limited in assessing asymmetries in the sprint start as the presence of the electrodes may change the behavior of the sprinter in the starting blocks. It would be more advantageous to use a technique to assess sprint start RT that interferes less with the movement.

A technique that did not involve attaching wires to the sprinters was developed by Sanderson, et al. (1991, 1996a&b). They incorporated a force/time-measurement device into a set of starting blocks. The device has gained some notoriety as the Saskatchewan Sprint Start System. The system involved the synchronization of strain gauges mounted to the pedals of a standard sprinter's starting blocks. The system allowed for fast and accurate force time/data to be collected in a variety of settings (both field and laboratory)

and to give immediate feedback to the sprinter. Force curves were used as a marker of RT. In addition, the Saskatchewan Sprint Start System included biomechanical measurement of the sprint start response. The system captured the entire block phase of the start, but is limited in that force is used as a measure of RT. It is possible movements occur before the first recorded change of force. In competition, to control for false starts, the IAAF uses force as their measure of time.

Although the Saskatchewan Sprint Start System (Sanderson et al., 1991; 1996a&b) is thought of as the most complete analysis system for the sprint start, Henry (1952) was one of the first to measure the horizontal forces generated during the sprint start. He did so by using a rack and pinion system that allowed him to measure the horizontal force for each leg throughout the start. The back leg was found to generate greater peak forces. The lead leg was found to generate greater impulse (as the foot remained in contact with the blocks longer thus increasing the time of force application). Henry's study was the first to analyze the role of each leg during the sprint start. While force magnitude and important information on initial foot action were gained, the study was limited in specificity. The rack and pinion system was effective for force measurement but was not a starting block. Therefore an approximation of the sprint start was measured rather than an actual sprint start.

More recent studies (e.g., Lemaire & Robertson, 1990) further analysed the application of force during the sprint start. Acquisition devices contained strain gauges of various configurations in order to record the forces created

during the block start. They developed devices, using strain gauges, to measure force application for each foot on a set of pedals. Although the device more closely resembled the sprint start, the ecological validity could still be questioned, as the devices were not proper starting blocks. As a result, their force data was somewhat limited in assessing the sprint start response.

The existence of manual and pedal RT asymmetries has been established in aiming tasks. Determining the nature of asymmetries in specific sport motor skills may impact the way the skills are taught. Asymmetries have not been analysed in the sprint start response. Examining the presence of RT and MT asymmetries in the sprint start response would provide further support for pedal asymmetries in motor skills. In order to study asymmetries, sprinters will be required to use both left and right rear leg block configurations.

The purpose of this study was to determine if pedal asymmetries in reaction time, movement time and response time exist in the sprint start response. As many sprinters are highly practiced in the sprint start in their preferred stance, a group of novice sprinters were used to insure that the results were not due to potential practice effects associated with experienced sprinters.

Methods

Participants

Twenty Lakehead University students volunteered to participate in the study (ages 19-34, mean = 23.4). Ten had a minimum of one full year of competitive starting block experience and were designated as the experienced

sprinter group. Ten participants had no starting block experience and were given sufficient explanation of execute the sprint start movement. Of the experienced sprinters seven preferred right foot starts and three left foot starts. In the inexperienced sprinters six preferred right foot starts and four preferred left.

Apparatus

Starting blocks were mounted over an Advanced Mechanical Technology, Inc. (AMTI) force plate (Model # OR6-5-1 Biomechanics Platform) with six load cells (Fz, y, z and Mx, y, z) into a 4'x6' plywood frame, from which a square section was cut out to surround the force platform. A riser plate for the force platform was inserted into the opening to contact the base of the blocks (see figure 3 for set-up). The force platform was connected to an AMTI 6 channel amplifier (Model # SGAG -4) with a gain of 2000 and a filter frequency of 1000hz. The vertical force channel of the amplifier was connected to channel 01 of a 14 channel 12bit DT 2001 A/D converter outputting to a computer. The signal was interpreted using the Global Lab software. A second computer was used to run a customized software program developed in the Lakehead University Biomechanics and Motor Control Laboratory (Eikenberry & Zerpa, 2005). The software was written in the Visual C++ language and the software contained three modules. Module 1 was data entry, to record participant numbers and information. Module 2 was a random number generator function to generate a pseudo-random order of the four possible foreperiods (1500, 2000, 2500 and 3000ms). Module 3 was a signal output function. The software ran blocks of 12

trials where each foreperiod occurred three times within a given block (in a pseudo-random order). At the beginning of each trial, a list of the 12 foreperiods was displayed for the researcher. Following a key press, an auditory tone was produced to represent the “set” command (50Hz) for an 80ms duration, following the variable foreperiod, a second tone was produced (100Hz) for an 80ms duration to represent the starting gun. Simultaneous to the first tone, a pulse (5V) was sent out via the LPT 1 (279H) parallel communication port, accompanying the second tone, the pulse was offset to 0V. The LPT 1 (279H) parallel communication port was connected to channel 00 of the 12 bit DT 2001 A/D converter and also interpreted in the Global Lab Software. Participants were instructed to ensure that both pedals for the blocks are on top of the force platform. The frame was bolted into the floor surrounding the platform to ensure that it did not move. For the safety of the participants, there were crash-mats placed at the end of the laboratory in case of collisions at the end of each trial.

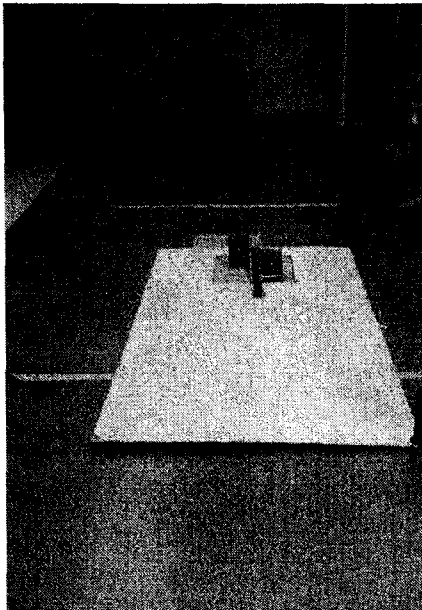


Figure 3. Starting block and frame set-up.

Reaction times, response times and movement times were recorded using the Global Lab software package derived from the force curves generated from the Force Platform at a sampling frequency of 1000Hz. Reaction time was recorded as the first change in force after the gun (with a threshold of 10mV or 16.55N). The end of movement time was recorded as the instant when force returned to zero.

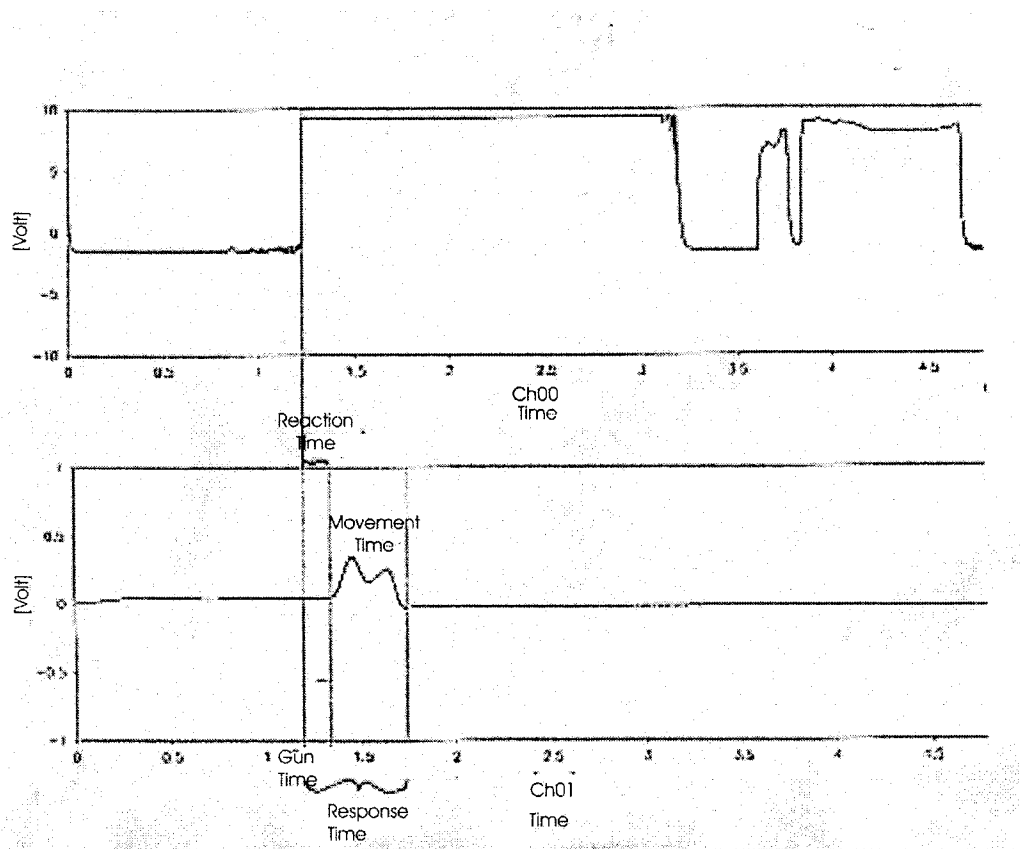


Figure 4. Sample Global Lab Output

Procedure

Participants completed two sessions (on separate days) of twenty-four trials; each consisting of 12 right leg starts (right foot in rear) and 12 left leg starts (left foot in rear). Prior to the first session, participants were given an explanation

of the study and informed consent was obtained. Participants then indicated their preferred rear leg (right or left), with inexperienced sprinters selecting a stance based on comfort. The order of leg use was varied between participants in a counterbalanced fashion. Participants were required to warm up prior to each session (ten minutes of easy running and five minutes of stretching). They then adjusted the starting blocks to a comfortable position (providing the proper leg orientation is present) prior to the first block of trials (the same block spacing was recorded and maintained for subsequent blocks). Each participant was allowed three practice starts at the beginning of each block of trials. Following the practice trials the researcher informed the participant to “stand behind your blocks”. A three-command start (as per IAAF guidelines) was used. A verbal on your marks command was used. The “set” command was given via computer recording in the form of an auditory tone (50Hz, 80ms in duration) followed by a second tone (100Hz, 80ms in duration) representing the gun. Periods for which the sprinter was held in the “set” position was varied (1500ms, 2000ms, 2500ms or 3000ms) pseudo-randomly to prevent anticipation. Each session had each of the four foreperiods occur three times in a pseudo-randomized order. On the starting signal, the sprinter was told to react as they would in a 100m race, and run hard for 5m, prior to decelerating. Following each trial, RT and MT data was recorded. In each session, twelve starts with one leg were completed prior to moving to the other leg. Each trial followed the same procedure.

False starts were recorded but did not count towards the 48 trials for this study. The International Association of Athletics Federations (IAAF) is the world

governing body for Track & Field. The IAAF's false start definition was used for the present study. The IAAF regulations (IAAF rule 161.2, 2004) state: "...the starting blocks shall be linked to an IAAF approved false start apparatus. The Starter and/or an assigned Recaller shall wear headphones in order to clearly hear the acoustic signal emitted when the apparatus detects a false start (i.e. when reaction time is less than 100/1000ths of a second)...".

Data Analysis

A 2 (foot preference: left and right) x 2 (group: experienced and inexperienced) x 2 (foot used: right or left) x 4 (foreperiod: 1500ms, 2000ms, 2500ms, 3000ms) mixed factorial ANOVA was performed for reaction time (false starts were excluded), movement time and response time. The foot-used variable and foreperiod were repeated measures in all groups.

Results

Reaction Time.

There was a significant main effect of foot use on reaction time $F(1, 19) = 118.147$, $MSE = .519$, $p < .001$ with the left foot mean reaction time (143ms) being faster than the mean right foot reaction time (169ms). This is the typical Asymmetry effect (see figure 5 for RT effects). There were no main effects for Foot Preference, Experience or foreperiod ($F_s < 1$) (see table 1). There were no interactions between any of the factors ($P_s > .05$).

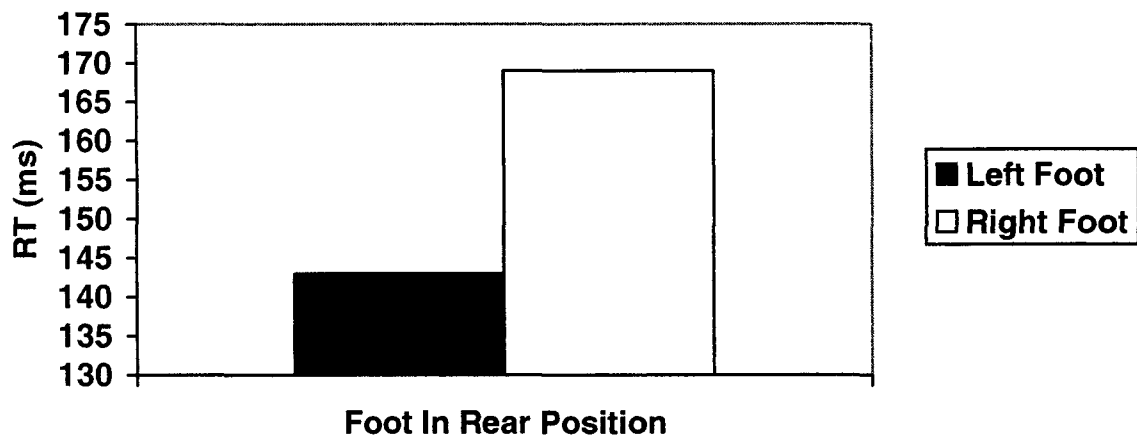


Figure 5. RT (ms) for the left foot in the rear position and the right foot in the rear position.

Movement Time.

There was a significant main effect of foot use of reaction time, $F(1, 19) = 235.963$, $MSE = 6.706$, $p < .001$ with the right foot mean movement time (508ms) being faster than the left foot mean movement time (612ms) (see figure 6 for MT effects). This follows the typical pattern of asymmetry. There were no significant main effects (see Table 2) for Experience, Foot Preference or foreperiod ($F_s < 1$). There were also no significant interaction effects ($P_s > .05$).

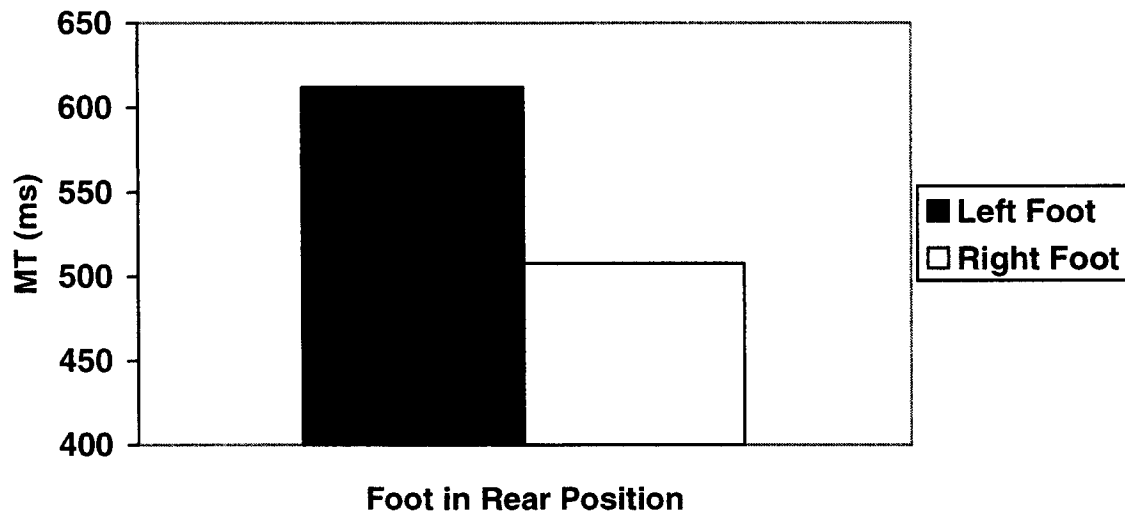


Figure 6. MT (ms) for the left foot in the rear position and the right foot in the rear position.

Response Time.

There was a significant main effect for Response time, $F(1,19)=293.082$, $MSE=10.127$, $p<.001$, with right foot mean response times (677ms) being faster than left foot mean response times (754ms) (see figure 7). There were no main effects for Experience, Foot Preference or Foreperiod ($F_s<1$). There were also no significant interaction effects ($P_s>.05$) (see table 3).

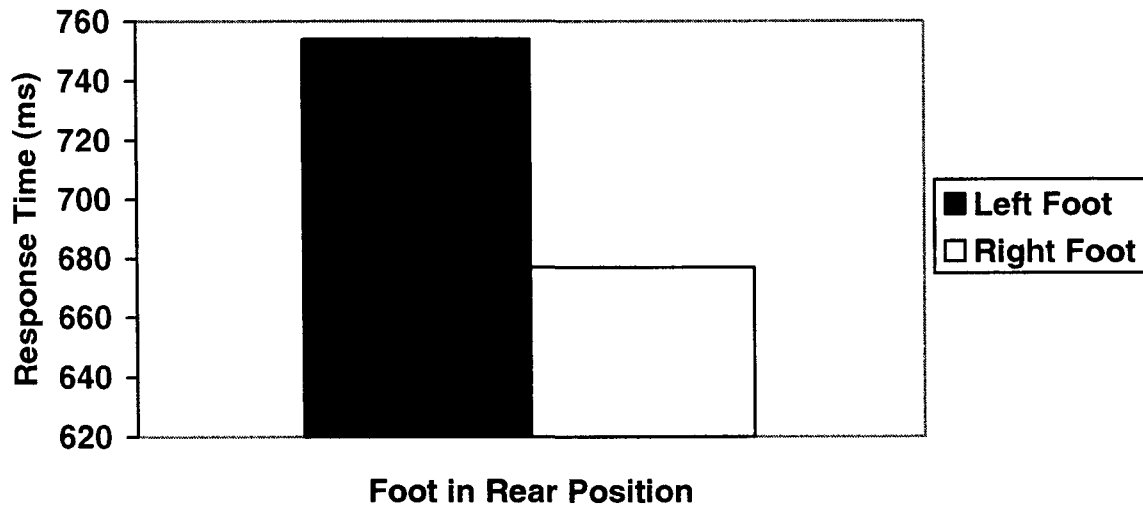


Figure 7. Response Time (ms) for the left foot in the rear position and the right foot in the rear position.

Table 1: Mean Reaction Time (ms) by foot in rear position, foot preference and experience level.

Foot in Rear Position	Foot Preference	Group	Mean (ms)	Std. Error
Right Foot	Left	Experienced	171	.015
		Inexperienced	182	.013
	Right	Experienced	167	.010
		Inexperienced	161	.011
Left Foot	Left	Experienced	169	.011
		Inexperienced	145	.009
	Right	Experienced	141	.007
		Inexperienced	130	.008

Table 2: Mean Movement Time (ms) by foot in rear position, foot preference and experience level.

Foot in Rear	Foot		<u>Mean (ms)</u>	<u>Std. Error</u>
<u>Position</u>	<u>Preference</u>	<u>Group</u>		
Right Foot MT	Left	Experienced	538	.033
		Inexperienced	505	.029
	Right	Experienced	482	.022
		Inexperienced	527	.023
Left Foot MT	Left	Experienced	587	.041
		Inexperienced	631	.035
	Right	Experienced	577	.027
		Inexperienced	652	.029

Table 3: Mean Response Time (ms) by foot in rear position, foot preference and experience level.

Foot in Rear	Foot		<u>Mean (ms)</u>	<u>Std. Error</u>
<u>Position</u>	<u>Preference</u>	<u>Group</u>		
Right Foot	Left	Experienced	709	.034
		Inexperienced	687	.030
	Right	Experienced	648	.022
		Inexperienced	689	.024
Left Foot	Left	Experienced	756	.037
		Inexperienced	776	.032
	Right	Experienced	718	.024
		Inexperienced	782	.026

Table 4: Mean Reaction Time (ms) by Foreperiod Duration.

<u>Foreperiod</u>	<u>Mean RT (ms)</u>
1500ms	162.825
2000ms	153.013
2500ms	151.854
3000ms	151.854

Discussion

The purpose of this study was to examine whether pedal asymmetries in RT, MT or response time exist in the sprint start response. A left foot advantage was found for reaction time, and a right foot advantage was found for movement time and response time. There were no effects of experience or foot preference. There were also no foreperiod effects.

There was a left foot advantage in RT. The left foot RT advantage supports a right-hemisphere specialization in stimulus processing. Specifically, it indicates a right hemisphere involvement in the detection and identification of the signal, as response selection and programming can occur *a priori* in an SRT.

The movement time advantage indicates a left-hemisphere specialization in the production and correction of the movement. The pattern follows Goodale (1998), Mieschke et al. (2001), and Boulinguez et al. (2000) findings. The nature of the movement in the sprint start was different than that in manual aiming tasks, reciprocal tapping and key press type movements. Aiming and key press movements are characterized by the use of fine musculature and

being very small movements. The track & field sprint start is a functional sport movement involving gross musculature. The presence of asymmetry in that context supports that the asymmetry pattern extends beyond just aiming movements.²

A right foot response time advantage was present. The advantage illustrates that in a gross movement, the impact of the movement time is more significant than the impact of the reaction time. In the present investigation, regardless of foot preference, the sprinters cleared the blocks faster with their right foot in behind.

The asymmetry effects were consistent with Carnahan and Elliot (1987), as a left-foot reaction time advantage and right foot movement time advantage were present. The patterns of advantage mirror studies on manual asymmetries (Goodale, 1998; Boulinguez, et al., 2000; Chapman, et al., 2001). The findings support the presence of pedal asymmetries similar to those found in the hands. Similar to Carnahan and Elliot, the asymmetry effect was found in a bipedal response. The findings are also similar to Neely et al. (2005), who produced asymmetry in bimanual responses. Neely et al. (2005), however, did not produce the movement time effect found in the present study.

Similar to Lavrysen et al. (2003), an auditory start stimulus was used in the study. With the auditory start stimulus, the asymmetries were still present, thus, the origin of the asymmetries is not solely due to the processing of visual information. Some asymmetry explanations (Boulinguez et al., 2000) suggested

² Bipedal force readings were used in the study, thus differences in force between the legs could not be examined.

that the asymmetries were partially due to allocation visual attention. The appearance of asymmetry with an auditory stimulus suggests that the role of visual attention in the mediation of asymmetry may be diminished. An auditory stimulus would suggest that the asymmetry is not only due to visual hemi-field or visual attentional origin. As the starting signal was presented dichotomously, the asymmetry is likely independent of hemi-field differences in the processing of the stimulus. The RT advantage could also be the result of a tighter stimulus-response link that is mediated by attentional processes (see Welsh & Elliott, 2004). That is the right-hemisphere's specialized role in attention creates a tighter stimulus response link. Other evidence suggests that the RT advantage may result from the right hemisphere specialization in the processing of meaningful non-verbal sounds (Lerbun et al., 2001) which would suggest that the left foot RT effect is due to more efficient stimulus identification and the MT effect is due to a left-hemisphere involvement in movement production

Variable foreperiods were used to prevent anticipation of the imperative stimulus. The foreperiods did not have an effect on Reaction Times (see Table 4). Since the reaction times were similar across the foreperiods, there was no significant anticipatory advantage for any delay. The foreperiod lengths were selected based on observation of video tape taken from the range of delays used by starters at the 2001 IAAF World Championships for the 100m heats. There was also no aging foreperiod effect, as reaction times were not significantly different for any of the foreperiods. The lack of significant difference suggests

that the variable foreperiod was effective in preventing anticipation of the imperative stimulus.

There was no effect of experience on reaction time, movement time or response time. While Lavrysen et al. (2003) found that asymmetry could not be practiced out, they did not use a well-practiced sport movement. Since the sprint start is a well-practiced sport movement, a novice and experienced sprint group were used. No significant differences were found between the groups, which, indicates that regardless of the degree of practice, the asymmetry effects are resilient in the sprint start.

The preferred stance was subjectively indicated in this study, and a measure of footedness was not used. Foot preference had no significant effect on the results. Such a finding follows the idea that right and left-handers are cerebrally organized in a similar manner (Herron, 1980). The lack of an effect of preference mirrors the manual research, where asymmetries were found to be similar in right and left-handers (Boulinguez, et al., 2001). The absence of the foot preference effect suggests that the asymmetry effects are due to cerebral organization rather than preferred stance.

Similar to the Saskatchewan studies (Sanderson, et al., 1991, 1996a&b), the present experiment used force as a measure of time. Force is the variable the IAAF uses in measuring RT for false starts. However, the present investigation was limited in that force was measured bipedally rather than separating the feet.

The applied findings to the track & field sprint start raise a number of issues. There was a left foot RT advantage, and a consistent MT and response time advantage when starting with the right foot in the rear suggests a possible implication on teaching and coaching. The MT and response time advantage means less time is spent in the starting blocks potentially giving an advantage to a sprinter starting with their right foot in behind in the blocks. In training sprinters, such an advantage would suggest that it might be advantageous to teach them to start in the right foot configuration for optimal performance. Both experienced and novice sprinters could benefit from the switch, as the effects were seen across both groups.

To completely understand the nature of pedal asymmetries further research is required looking at everyday movements. The addition of cerebral imaging would also provide further insight into the origin of the asymmetries. In the sprint start realm, force amplitudes and final or 10-30m performances need to be examined in addition to the sprint start timing to determine the overall effect of the asymmetry on race performance. Force readings for the feet should also be investigated using separate force measuring devices for each foot to isolate their data.

Pedal asymmetries in RT, MT and response time were found in the track & field sprint start response. There was a left foot RT advantage and a right foot MT and response time advantage. The advantages support the hemispheric lateralization model (Welsh & Elliott, 2004).

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Appendix A
Definitions of Terms

Definitions

False Start: Any start where RT is shorter than 100ms (IAAF rule 161.2, 2004).

Foreperiod: The time between the warning signal and the presentation of the imperative stimulus (Niemi & Naatanen, 1981).

Movement Time (MT): The time from the first sign of overt movement until the end of the movement (Schmidt & Wrisberg, 1998). In the sprint start, movement time is the time from the first change in force until force returns to zero (sprinter has exited the starting blocks).

Reaction Time (RT): The time from stimulus presentation until the first sign of overt movement (Schmidt & Wrisberg, 1998). In the sprint start, reaction time is the time from the sounding of the gun until the first change in force.

Response Time: The time from stimulus presentation until the end of the movement, $RT + MT$ (Schmidt & Wrisberg, 1998). In the sprint start, the time from the starting gun until the instant where the sprinter exits the starting blocks.

Warning Signal: A cue presented to indicate that the imperative stimulus will follow (Niemi & Naatanen, 1981). For example, in the sprint start, the warning signal is the set command

Appendix B

Limitations and Delimitations

Delimitations

This experiment is delimited to:

- The track & field sprint start response.
- 20 participants, of which 10 have at least one full season of sprint racing experience using starting blocks, the other 10 have no experience or formal coaching in starting block use.
- A convenience sample from the population of sprinters in Thunder Bay, Ontario, Canada.
- Force used as a measure of time (changes in force used to indicate reaction, movement and response times), force magnitudes were not examined.
- Bipedal reaction times

Limitations

This study is limited by:

- The data collection will occur in the laboratory setting, thus environmental factors such as wind and external noise will not be present as they would in a sprint race
- The abilities of sprinters in Thunder Bay, Ontario, Canada
- The use of a simulated starting mechanism rather than a starter's pistol (as to avoid eliciting startle responses)

- The data collection device precludes the ability to distinguish between pre-motor and motor components of total Response Time.
- Bipedal reaction times

Appendix C

Review of Literature related to sprint starts, simple reaction time and manual asymmetries

Introduction

Sprint races have long been the focus of attention in track & field. Often decided by matters of milliseconds, time saved during the start becomes important. While many sports use sprint starts of differing techniques, the nature remains to respond as quickly as possible to the starting stimulus. While the sprint start is important, little is known about the response itself. Many studies have examined aspects of the sprint start, however, few have examined the response as a whole. The sprint start is considered to be a simple reaction time task with the objective to respond as quickly as possible to the starting gun. No choice is present in terms of response selection, once the runner enters the “set” position; the only option is to start.

How do our hand systems differ? Are certain tasks more suited to one hand or the other? The topic of asymmetries between the left and right hand systems has been the subject of recent research. Further, asymmetry has yet to be examined in a functional movement. The track & field sprint start provides an example of a functional movement that can be used to further examine the nature of hemispheric lateralization.

This paper examines the manual asymmetry literature to gain an understanding of asymmetries. Pedal asymmetries were also examined.

Methods

Searches were performed using the Sportdiscus, PyschInfo and Pub Med databases using the keywords “Sprint Start”, “Simple Reaction Time” and “manual asymmetries” for English language papers, all years were examined, but an emphasis was put on recent studies. Articles were excluded from the sprint start section if they did not pertain to a block start, or were kinetic/kinematic analyses of sprint starts in other sports. Non block starts were excluded as it is difficult to define a start and end point for the response. Sprint articles were also excluded if their focus was on the sprint after exiting the blocks rather than the start. Simple reaction time papers were excluded if they were performed with non-human participants or participants with psychological or pharmacological conditions as these have been shown to interfere with these tasks. Articles were excluded if they were related to traditional hand dominance, rather than cognitive processing and movement execution.

Articles reviewed were limited to those that could be obtained from Lakehead University's library, and via their Racer system for interlibrary loan.

Results

Sprint Start

Henry (1952) measured the horizontal forces generated during the sprint start. Using a rack and pinion system that allowed measure many of the horizontal forces, each leg was analyzed throughout the start. Greater peak forces were generated by the rear leg. Greater impulse was generated by the lead leg, as the foot remained in contact with the blocks longer (increasing the time of force application). This study was the first to analyze the role of each leg during the sprint start. While force magnitudes and important information on initial foot action were gained, this study was limited in specificity. The rack and pinion system was effective for force measurement but was not a starting block. Therefore an approximation of the sprint start was measured rather than an actual sprint start. This system was also confined to the lab setting, and could not be used in the field.

Lemaire & Robertson (1990) designed a device with replaceable blocks (for different obliquities) that had a metal rod, 15cm long, with four strain gauges in a full Wheatstone bridge. Bars were threaded for attachment to (5cmx10cm) aluminum end plates, which were then attached to the blocks. There were separate units for each foot, and were then mounted to a support board. The signals were amplified and analyzed via computer. Lemaire and Robertson's (1990) device was able to collect and provide accurate force/time data. While the device resembled a starting block, it was not one.

Sanderson, McClements & Ganders (1991) finally produced a device that could measure the sprint start response more accurately. They took actual starting blocks and mounted their strain gauges in the pedals. Their configuration allowed the measurement of forces and time without disturbing the sprint start. The device was both portable, and accurate. Later studies, by McClements, Sanderson & Ganders (1996a&b) further tested the device.

In their first study, McClements et al. (1996a) used the device to design a predictive model for sprint performance. Their study found that accurate maximum vertical and horizontal forces were the best predictors of sprint performance. They also found that providing rear block reaction time feedback helped maximize force production without lengthening block contact time.

In their other study, McClements et al. (1996b) used their Saskatchewan Sprint Start System to provide feedback in order to improve performance. After 40 training trials, a significant difference in performance improvements was found between the feedback and control group, with an advantage in 20m-sprint time improvement found for the feedback group.

Other studies have examined the biomechanics of the sprint start. Technical examinations were conducted to find optimal block positioning. Schot and Knutzen (1992) looked at 4 different positions including bunched and elongated both in a perpendicular (arms 90degrees to the track) and forward position (shoulders forward, arms 80 degrees from forward horizontal to the track). They found that the bunched starts yielded faster departures from the starting blocks. The elongated positions yielded greater departure impulses. No

significant differences were found with arm positioning. Alone, the study could not suggest which positioning would be optimal for performance. When viewed with the findings from McClements et al. (1996a), one could hypothesize that the lengthened block exposures of the elongated positions would yield greater performance, as they generated greater forces. Harland and Steele (1997) performed similar analyses focused on block spacing.

Harland and Steele (1997) examined block spacing and arm loading during the sprint start. Their analysis involved examining the existing base of research and combining results in order to obtain a more comprehensive view of the sprint start. Their findings were similar to Schot and Knutzen (1992) and McClements et al. (1996a) in that horizontal velocity was a key contributor from the sprint start to overall sprint performance. Harland and Steele (1997) also found no advantage in forward body posture as increasing arm loading contributed little to sprint performance. Their findings suggest medium block spacing is best, as it provides a middle ground between the quick exit of the bunched start and the increased force production of the elongated positions.

Another project set to analyze the sprint start in order to enhance performance is the F.A.S.T. (Flanders athletic sprint team) project (Delecluse, Diels, Goris & van Coppenolle, 1996) in Flanders. Their study examined the sprint start data of four elite female sprinters in hopes to find trends to help improve their own group of sprinters. Delecluse et al. (1996) noted great individual differences even among a group of world-class sprinters. Consistently, the rear foot left the block first with horizontal velocity primarily dependent on

front foot contact time. Thus, those with shorter duration of block contact generated lower front foot impulse, and lower horizontal velocities. Interestingly, the same sprinters with shorter block times generated greater rear foot impulses, as their rear foot block times were longer. The project is on-going with their athletes being tested 3 times annually.

The timing of the sprint start was also examined using electromyography (EMG) by Mero and Komi (1990). Mero et al. (1990) used two groups of sprinters, one with EMG surface electrodes on their front leg, the other on their rear leg. Five muscle sites were used, including the Gastrocnemius (lateral muscle belly), vastus lateralis, biceps femoris (long head), rectus femoris and gluteus maximus. Total reaction time (TRT) was divided into two components, pre-motor time (PMT), and motor time (MoT). PMT is the time from stimulus movement to the onset of EMG activity. MoT is the time between PMT and onset of movement as recorded with the force platform. Mean total reaction time for both groups was 121ms, a value faster than those recorded at most major championships (Moravec, Ruzicka, Susanka, Dostal, Kodejs & Nosek, 1988)³. The rear leg was found to react quicker than the front leg, similar to Henry (1952). Further, the gluteus maximus was found to have the shortest PMT in the rear leg and the gastrocnemius in the front. Mero et al. (1990) also found a mean motor time of 27.7ms. As a result, it is suggested that the largest portion of the TRT is pre-motor, and a relatively short delay from muscle electrical stimulation to movement production. The study also compared force amplitudes between muscles. Given that EMG impulses are relative, data drawn from such

comparisons holds little meaning. If one sought to compare EMG between muscles, a percentage of maximum contraction value would have to be generated, only then allowing some form of comparison. The study was successful at splitting the sprint start reaction time into pre-motor and motor components. Insight was provided for EMG electrode placement in future studies. The role of psychological focus on the sprint start has also been examined.

Buckolz (1980; Buckolz & Vigars 1987) studied the psychological allocation of attention during the sprint start. These papers examined whether it was better to attend to rapid initiation of the movement, movement execution details (both considered 'Motor sets') or to the gun (starting stimulus) itself ('sensory set'). An argument was made in favor of the sensory set, although they found that people were naturally biased towards one of those strategies already, and thus those who followed their normal strategies produced the best results. Their data was collected via a load cell attached to the back of the starting blocks.

Simple Reaction Time

Prior to discussing simple reaction time (SRT), the terms reaction time and simple reaction time should be defined. Reaction time refers to the time from stimulus presentation (e.g., the firing of the starting gun) until the first sign of overt movement (Schmidt & Wrisberg, 2000). Reaction time reflects the time needed to process the stimuli and program a response. Simple reaction time can be defined as reaction time where there is only one possible outcome, or reacting

³ The minimum legal reaction time in the sprint start was 120ms at that time (Mero & Komi, 1990).

in the absence of response uncertainty (Henderson & Dittrich, 1998), as temporal uncertainty still exists. Simple reaction time becomes simpler in the absence of temporal uncertainty, as anticipation is possible. To control for anticipation, variable fore-periods (between warning and go-signal) or catch trials (trials where a warning is presented, with no go signal) are necessary (Polzella, Ramsey & Bower, 1989).

In simple reaction time tasks, there is generally a warning signal followed by a delay, followed by the starting stimulus. The delay between the warning signal and the starting stimulus is called a foreperiod. If the foreperiod is consistent, it becomes easy to anticipate (Requin, 1985). A variable foreperiod is often used to eliminate the effects of anticipation (by creating temporal uncertainty) (Niemi & Naatanen, 1981). Foreperiod has been shown to have an effect on SRT. When there are a limited number of equiprobable foreperiods, as time continues between presentation of the warning signal and the starting stimulus, reaction time becomes quicker. The probability of the response stimulus being presented increases as the foreperiod continues. Conversely, as foreperiod lingers onwards, the participant's timekeeping ability decreases. A decrease in relative time keeping ability makes it difficult to anticipate the starting stimulus (Niemi & Naatanen, 1981; Naatanen & Merisalo, 1977). Stimulus intensity has also been shown to impact SRT.

Niemi and Lehtonen (1982) examined the relationship between foreperiod and stimulus intensity. Both visual and auditory modalities were

examined. They found that as stimulus intensity increases, simple reaction time decreases.

Recently, studies in simple reaction time have shifted from behavioral to neurological examinations. The new approaches have led to newer perspectives, such as hemispheric advantages. It is suggested that the right hemisphere holds an advantage in reaction time due to specialization towards spatiotemporal tasks (Braun & Daigneault, 1994). In 1993 Braun performed a meta-analysis of 47 simple reaction time studies and suggested that two channels for inter-hemispheric relay existed, a fast and a slow one in both directions. These studies used crossed-uncrossed differentials (CUD) to calculate inter-hemispheric transfer times (IHTT). CUD refers to the difference between trials where the input and response used different hemispheres (crossed) and trials where the same hemisphere (uncrossed) was used to process the stimulus. The difference between the two represents the IHTT. Meta analysis led to a prediction of a right field advantage, a faster reaction time to objects in the right visual field. Braun and Daigneault (1994) performed a follow-up study. This study used a computerized SRT paradigm to verify this model. Braun and Daigneault (1994) found that the fast channel operated when one hemisphere is specialized for a particular task (thus if a right hemisphere task required a right hand response, the information would cross via the fast channel). Thus since the right visual field is controlled by the left hemisphere and the right hemisphere is specialized for spatiotemporal tasks, the fast channel is used to relay the input (fig. 1). If the

input was in the left visual field and the output required right hand use, the reaction time would be slower as the slow relay channel would be used.

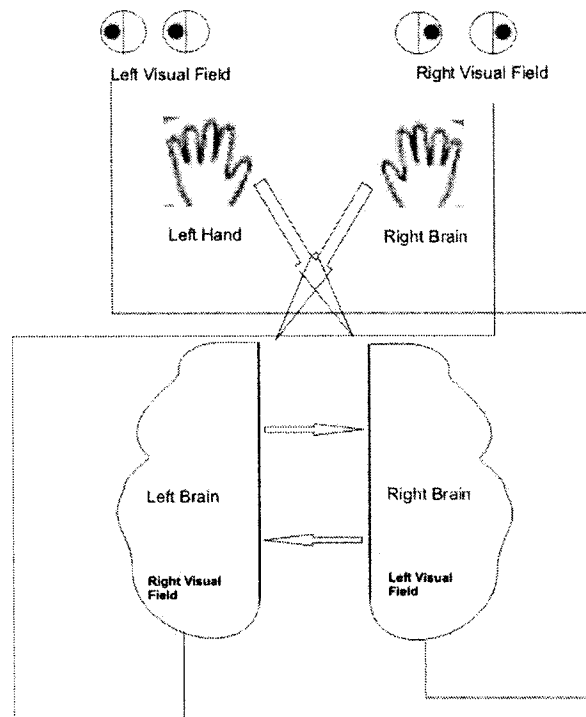


Fig. 1 Channels of inter-hemispheric relay.

Henderson and Dittrich (1998) suggested the key to simple reaction time was attention. They found that simple reaction time advantages over choice reaction time vanished if the participants were attending elsewhere when a stimulus was presented. The advantages were present when participant's attention was allocated to signal detection (of the stimulus). They suggested that while other options may be absent in a SRT task, if an attentional choice must be made between the stimulus and other information, the principles of choice reaction time would still apply.

Electrical mapping during visual SRT has also been performed. Murray, Foxe, Higgins, Javitt and Schroeder (2001) used visual evoked potentials (VEPs)

to map out electrical stimulation during simple reaction time. Murray et al. (2001) divided the visual field into upper and lower, right and left quadrants. They found reaction time facilitation when stimuli were presented in multiple quadrants simultaneously. Greater facilitation was present when stimuli were in the same hemifield, but both upper and lower quadrants. The major limitation to the study is that it is not purely a simple reaction time task. Central fixation was required with different possible stimulus presentation locations, thus a choice was present as to eye movements, as the set-up did not preclude small eye movements. While the only possible outcome was to respond to a presented stimulus, attentional choices were present, thus, according to Henderson and Dittrich (1998), the task resembles choice reaction time, rather than simple reaction time.

Corballis (2002) performed another study on hemispheric interactions in simple reaction time tasks. This study used two different stimulus intensities, as well as analyzing CUD. The CUD analysis yielded similar results to Braun and Daigneault (1994), however, the more salient finding was regarding stimulus intensity. Holding with what is known on signal detection, the higher contrast condition yielded faster simple reaction time than the low contrast condition. The findings suggest that stimulus intensity is a key factor in simple reaction time. If the stimulus cannot be detected, there is nothing to react to. In another similar study, Ulrich and Mattes (1996) conducted 3 experiments to determine effects of arousal on simple reaction time. In their first experiment, Ulrich and Mattes (1996) manipulated warning signal intensity, as it has been linked to arousal (Bertelson & Tisseyre, 1969). A positive relationship was found between warning

intensity and faster reaction times were found. Thus, a stronger warning signal would lead to increased arousal speeding reaction time. In the second experiment, Ulrich and Mattes (1996), warning signal duration was manipulated. Longer durations led to slower, but more forceful reactions, while the reverse was found with shorter warning signal durations. Both of these findings support the idea that arousal speeds reaction time. Such findings also support Buckolz and Vigars (1987) findings in the sprint start, where those attending to the sensory set (arousal towards auditory stimulus) led to faster reaction times. In their third experiment, Ulrich and Mattes (1996) employed a visual warning signal. They manipulated the brightness of the warning signal. The manipulation did not lead to reaction time effects as were found in the first two experiments. Since the go signal was auditory, Ulrich and Mattes (1996) suggested that it might be a stimulus response compatibility issue mediating arousal effects on simple reaction time.

One could suggest that the sprint start be contained under the umbrella of simple reaction time, as once in the set position, the only option is to start, thus, no choice is present. Conversely, it is also possible that the sprint start is a startle response to the gun, rather than a pure simple reaction time.

Manual Asymmetries

Most explanations of manual asymmetries stem from research which separates the hand/hemisphere systems (right hand/left hemisphere, left hand right hemisphere) on the basis of hemispheric specialization. The right hemisphere has been said to be specialized for spatial processing and

movement preparation, the left for movement execution (Carson, 1989). Much of the evidence comes from manual aiming studies. Manual aiming studies generally involve the presentation of cues followed by targets that a participant must point or reach to with one or both of their hands.

An alternative explanation for asymmetries is one that is attentional in origin. Elliott, Roy, Goodman, Carson, Chua and Maraj (1993) two experiments to examine the origins of manual asymmetries. Their first was a manual aiming study where they had participants make fast (250-350ms) and slow (450-550ms) aiming movements with their right and left hands towards a target circle or a dot. They found that in all conditions, the right hand made less error than the left. In the most difficult conditions, the largest right hand advantage was present. Elliot et al.'s (1993) finding was contrary to the spatial-complexity hypothesis that suggested that as spatial complexity increased, the right hand accuracy advantage would disappear. The evidence demonstrated the opposite effect with the right hand advantage increasing as the spatial demands increased. In their second experiment, they employed a choice reaction time manual aiming task. One condition required the participants to aim as quickly as possible, the other as accurate as possible. On some trials, lights were extinguished to eliminate visual feedback. Trials were started with an auditory tone that was either high (move to right) or low (move to left). Reaction time was consistently faster with the left hand. The advantage was at its greatest when moving ipsilaterally. The right hand moved more quickly to the targets than the left, with the greatest advantage found in ipsilateral space. The experiment determined that there was a left hand

advantage for spatial planning. The right hemisphere's control of the programming of spatial and perceptual task demands was suggested as a possible origin of this advantage. Since the left hand has more immediate access to the right hemisphere (direct connection as opposed to inter-hemispheric transfer), the advantage is evident when rapid spatial and perceptual demands are present. The experimental design was such that it could not be determined whether the left hand advantage was due to the right hemisphere's specialization in establishing spatial location or in the planning of the goal directed spatial organization. A right hand advantage was found in movement execution. The advantage was attributed to the left hemisphere's specialization in the control and organization of sequential movement.

Roy, Kalbfleisch and Elliot (1994) examined the right hand accuracy advantage. They used a manual-aiming paradigm to examine differences in how the hemisphere-hand systems dealt with visual feedback. They were able to reproduce the right hand advantage in both accuracy and in movement times regardless of whether visual feedback was present or not. Such a finding was contrary to their hypothesis that the left hemisphere was faster at dealing with visual feedback, leading to the right hand advantage. A suggested explanation was that the left hemisphere required less information on which to base corrections. Further, it was suggested that the right hand system may be more effective at using feed-forward predictive control.

Carson, Chua, Goodman, Byblow and Elliott (1995) also studied manual asymmetries. In three different aiming experiments, Carson et al. (1995)

controlled different parameters to find an explanation for asymmetries. They found a consistent left hand reaction time advantage, except when movement accuracy was emphasized. They also found consistent accuracy advantages for ipsilateral movements with each hand (due to visual field lateralization see fig. 1). The reaction time advantage was attributed to the right hemisphere's specialization in movement planning. When accuracy was emphasized, more emphasis was shifted to on-line correction, eliminating the left hand advantage. They also acknowledged the possibility that the asymmetries present in their simple reaction time condition could be due to the allocation of attention following their pre-cue. The right hand showed a consistent advantage in accuracy throughout the three experiments.

Carnahan (1998) further investigated the origins of the right hand advantage. Participants were required to perform aiming movements to one of three targets. In "perturbed trials", the target would change prior to the movement being complete. In the normal trials, there was a mild right hand advantage in movement time and accuracy. When the targets were perturbed, the advantage became more pronounced. The initial reaction time in both trial types favored the left-hand. They attributed the finding to the right hemisphere/left-visual field advantage for spatial decision making. In the second experiment, Carnahan (1998) examined the asymmetries in response to target perturbations when the participants were asked to reach and grasp. No significant effects could be reported other than a small advantage in the left hand at grasping towards the left target. No effects were found when targets were perturbed. It was suggested

that if the precision of the grasping movement were enforced, a right hand advantage might have surfaced. The two experiments suggested that when either hand was used both hemispheres contribute to the movement via inter-hemispheric communication. The advantages were due to direct connections to the hemisphere specialized for that aspect of the response.

Binstead, Cullen and Elliott (1998) used two experiments to examine the role of feedback, as well as asymmetries in movement variability in manual asymmetry. Participants had to point to illuminated targets pressing against a force bar. In this experiment, no hand advantages were found. Contrary to their hypothesis, there was a trend for the left hand to produce a more consistent output, however, it failed to reach significance. In their second experiment, participants had to generate forces of different magnitudes against the force bar with each hand. Again, they failed to produce any asymmetries between the two hands. They also failed to support their motor output hypothesis. This hypothesis states that the right hand/left hemisphere system accuracy and movement time advantage was due to less movement variability.

Buekers and Helsen (2000) further examined the role of visual feedback in the right hand advantage. They formulated two manual aiming experiments to test this hypothesis, using full and intermittent vision. Their first experiment did recreate the typical right hand movement time advantage, but found no interaction with the visual condition. This lack of interaction suggested that the right hand advantage might not be mediated by a left-hemisphere advantage in the use of visual feedback. Their second experiment was similar to the first,

except that it involved rapid reciprocal tapping. The reciprocal task was used to verify if the failure to find the visual condition effect was due to task simplicity. Again, they failed to find an interaction of degraded vision with the asymmetry between the two hand systems. Again, a right hand movement time advantage was found. Their findings in both experiments failed to support their hypothesis that the right hand system advantage was due to more proficient processing of visual feedback, as asymmetry did not increase when the visual feedback was degraded. Left hand movement time did increase as the visual feedback was degraded, however, right hand movement times increased correspondingly.

Manual asymmetries in movement organization as a result of the movement parameter being controlled have also been examined. Boulinguez, Barthelemy and Debu (2000) did so by measuring reaction time while controlling movement time and amplitude to a target in a manual aiming task. They produced a consistent right hand advantage in movement times. Since their sample was comprised of right-handers, they attributed the advantage to the amount of practice participants have aiming with their preferred hand over their non-preferred. Thus, they suggest the difference in movement times were due to biomechanical and/or muscle adaptations to the use of the preferred hand. They also produced a consistent left hand advantage in reaction times. They suggest that there may be visual attention mechanisms at play in the left hand reaction time advantage, specifically in the processing of visuospatial information. The difference between the hemispheres being equated to inter-hemispheric transfer

time, for the information from the right hemisphere to traverse to the left so that it could be sent out to the right hand.

With much of the asymmetry research conducted on right-handers, one begs the question if the same phenomenon exists for left-handers, or if their asymmetries were different. Boulinguez, Nougier and Velay (2001a&b) conducted a series of experiments with right and left-handers to examine this. The first set of experiments (Boulinguez et al, 2001a) was conducted on right-handers. They used double step pointing tasks to examine the manual asymmetries. The first experiment focused on the control of movement direction. They produced the traditional left hand reaction time and right hand movement time advantages both in the perturbed and non-perturbed conditions. The second experiment controlled movement amplitude rather than direction. In this experiment they failed to yield a reaction time advantage for either hand. They did produce a movement time advantage, however, it was for the left rather than the right hand. They also found a left hand advantage in time to trajectory correction. They suggested it may be due to control of the movement amplitude being less constraining than control of movement direction. Inconsistency led them to suggest that depending on movement constraints, different types of hemispheric preference were present. They were unsure whether such findings applied to both left and right-handers, as this study only employed right-handed participants.

Boulinguez et al. (2001b) analyzed whether handedness interacted with these findings by using left-handed participants. The first experiment mimicked

the one used in their study of right-handers. They produced a left hand advantage in the control condition (single step reaching) but not in the experimental condition of double step reaching. In unperturbed experimental trials, they found the right hand had the traditional movement time advantage that has been found in right-handers. The advantage disappeared in the control condition. While the mechanisms found were similar to those of right-handers, they found that left-handers were less skilled when using their non-preferred hands, even if they were quicker to correct errors. The second experiment mimicked their second one with right-handers (Boulinguez et al, 2001a). In this experiment, no reaction advantage was found. They did find a movement time advantage for the left hand, converse to the findings with right-handers. They suggested that multiple forms of differing motor asymmetries might exist, independent of handedness. The constraints of the task often mediate which hand is to be used. Further, they suggested that the same mechanisms were at play in both left and right-handers. Left-hemisphere (right hand) advantages were attributed to the hemisphere's dominance in temporal processing of movement related information. The right hemisphere (left hand) was suggested to be dominant in spatial processing (movement planning).

Chapman, Heath, Westwood and Roy (2001) examined manual asymmetries when target location was defined through kinesthesia as opposed to visual information. They would guide the participants' hand to a target and hold it there for 2 seconds before returning it to the home spot. The participant would then face a delay of 1-10s prior to having to replicate the movement. They found

that contralateral movements with either hand were slower than ipsilateral ones. They found the right hand's performance didn't deteriorate as the delay increased while the left-hand did. They suggest that kinesthetically defined movement memory is more resilient for the right hand/left hemisphere system. They also suggested that there were two memory systems at play, one kinesthetic, that was limb specific and the other was visual, and accessible by both limbs.

Attention is a factor that may affect manual asymmetry. Mieschke, Elliot, Helsen, Carson & Coull (2001) examined a sample of right-handers using a rapid manual aiming and finger lift paradigm. They found a left hand reaction time advantage aiming to targets in the left visual space, but not the right. The left hand RT advantage and left hand MT advantage were both present. Their advantages were independent of the amount of pre-cue information presented. This supports the movement planning hypothesis.

To examine possible attentional origins of manual asymmetries, Barthelemy and Boulinguez (2002) employed a modified Posner (1980) task. They performed two experiments with small differences in task. Their first experiment had participants reach and point to the target, the second had them press a corresponding key. In the pointing task, they found left hand reaction time advantages. In their second experiment, requiring a simple key press they replicated this finding. They found that orienting visuospatial attention to the target location before detecting and pointing improved reaction time. If the visuospatial attention was oriented towards a false target location, reaction time

was slowed. The left hand was found to have faster reaction times only when attention had to be disengaged and shifted to a new location, suggesting that the left hand was more efficient with shifts in visual attention. The advantage is suggested to stem from the role that the right hemisphere plays in orienting visual attention. The right hand has a harder time dealing with the disengaging of visual attention, as it must rely on inter-hemispheric transfer, which is a slower process. In the key-pressing task, they found a left visual field reaction time advantage because of the general alertness advantage in the right-hemisphere. Thus, attentional origins of manual asymmetries cannot be excluded, as they appear to play an important role in goal directed hand movements.

Asymmetries in the transfer of learning between hand have also been examined (Lavrysen, Elsen, Tremblay, Elliott, Adam, Feys & Buekers, 2003). This was examined in combination with the one-target advantage. The one-target advantage hypothesis states that people initiate movements faster when there is only one target to move to, as opposed to two. This study used a manual aiming task to examine both phenomena. This study used both right and left-handed participants. They found a consistent one-target advantage as hypothesized, regardless of hand used and hand-preference. However, prior to practice, this advantage was not present in left-handers, suggesting that they favor a more on-line mode of control than right-handers. After training, regardless of the hand that was trained, the one-hand advantage was robust. During acquisition trials, they found a reaction time advantage for the left hand in both right and left-handers. Like Barthelemy and Boulinguez (2002), they attributed this to attentional

mechanisms, and the special role of the right hemisphere in the orienting and disengaging of visuospatial attention. Both groups exhibited a greater amount of transfer of training from their non-preferred hand to their preferred. Thus, right-handers experienced more transfer of training from their left hand to their right than vice-versa. Left-handers experienced the opposite, more transfer from their right to their left, then from left to right. Due to their initial approach during the pre-test, they concluded that left-handers are not simply the mirror image of right-handers. Different strategies were apparent to maximize their natural advantages.

Recently, Neely, Binstead & Heath (2005), examined manual asymmetries in bimanual movements. Neely et al. used a bimanual aiming paradigm with targets presented both contra and ipsilaterally initiated to an auditory tone. They produced a left hand reaction time advantage. They did not achieve a significant right hand advantage in movement time.

Pedal Asymmetries

Very little research has been done on pedal asymmetries. While much work has been done on the origins of their manual counterparts, most researchers have avoided examining asymmetries in the feet. While the same cross wiring of the arms is present with the legs, little has been done in this area.

Carnahan and Elliott (1989) examined pedal asymmetries in the reproduction of spatial locations. They used a pedal-aiming task, where participants had to aim at targets with their feet. Participants were blindfolded and told to move their left, right or both feet in abduction to various position (10,

20, 30 or 40 degrees from starting position). The participant would then return their foot to the starting position and wait for an auditory cue to reproduce the movement. They found the left foot of the participants both in single and double foot movements produced less error. The findings contrasted the findings in thumb movements of Roy and MacKenzie (1978), who found that they only produced this advantage when both thumbs were used simultaneously.

Carnahan and Elliott (1987) suggested that it was due to the fact that people are less trained at making aiming movements with their feet. Thus, the task is relatively more difficult with the feet, leading to the greater task difficulty and pedal asymmetries.

Conclusion

While many facets of the sprint start have been examined, the response as a whole has yet to be examined in one study. In order for an analysis of the sprint start response to be performed, actual starting blocks must be used. Without them, only an approximation of the response can be measured. There is also little research on pedal asymmetries. As a bipedal, simpler reaction time task, the sprint start response provides a good mechanism with which to examine pedal asymmetry.

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