SPRINTING KINEMATICS OF ATHLETES WITH SELECTED DISABILITIES

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

The purpose of this research was to gain insight into the sprinting of athletes with selected physical disabilities. The sprint performances of four Paralympic athletes (T43, T13, T37 and T38 classifications) were analysed in terms of variability in the biomechanics of their set position and in the kinematics of the initial acceleration phase and the maximal acceleration phase of their 100m sprints. The athletes also reported their perceptions about the potential of a rhythm training programme to influence their sprinting.

A case study approach was used. Sprint kinematics were video-recorded four times over the training year. DartFish ProSuite software supported the digital tagging of anatomical landmarks and the calculation of the biomechanical features of the set position as well as the kinematics of each athlete. A subjective log was used to gather their perceptions about the rhythm training programme.

There was variability in all aspects for all four Paralympic athletes. This should encourage coaches to help athletes find optimal kinematics in relation to their disability, rather than trying to coach them to a set template of an ideal form. Based on the kinematic data collected over all four test sessions, it appears that a coaching focus on stride length was the key to faster sprinting for this T43 (amputee) athlete. A coaching focus on stride frequency (once optimal stride length had been discovered) was the key for the T13 sprinter (visually impaired), and a coaching focus on stride frequency was the key to faster sprinting for both the T37 and T38 athletes (cerebral palsy). Although all of the athletes enjoyed the rhythm training programme, only the least experienced athlete (T38) reported that he would like to continue with this form of training.

Key words: Sprint kinematics; Sprint biomechanics; Paralympic sprinting

Die doel van hierdie navorsing was om insig rakende die naellooptegnieke van atlete met geselekteerde fisiese gestremdhede te verky. Die naellooptegnieke van vier Paralimpiese atlete (T43, T13, T37 en T38 klassifikasies) is ontleed. Die ontleding is gedoen met betrekking tot die veranderlikheid in biomeganika tydens hul gereedheidsposisies in die wegspringblokke asook in die kinematika van die aanvanklike versnellingsfase en die maksimale versnellingsfase gedurende hul 100m naelloopitems. Die atlete het ook hul persepsies rakende ’n ritmiese oefenprogram wat potensieël hul naellope kon beïnvloed gerapporteer.

’n Gevallestudiebenadering is gebruik. Beeldmateriaal van naelloopkinematika is vier keer gedurende die oefenjaar vasgelê. “DartFish ProSuite” sagteware het die digitale kodering van anatomiese punte ondersteun asook die berekening van biomeganiese eienskappe gedurende die gereedheidsposisie en die kinematika van elke atlete gefasiliteer. Daar is op ’n subjektiewe basis boekgehou van die atlete se persepsies rakende die ritmiese oefenprogram.

Daar was wisselvalligheid in alle aspekte met betrekking tot al vier Paralimpiese atlete. Dit behoort as aanmoeding vir afrigters te dien om atlete te help om optimale kinematika in verband met hul gestremdheid te vind, eerder as om die atlete volgens ’n vaste templaat of ideale vorm te probeer afrig. Volgens die kinematiese data wat oor die loop van al vier toetsingsessies ingesamel is blyk dit asof ’n afrigtingsfokus op treëlengte die sleutel tot vinniger naellope vir die T43-atleet (amputasie) was. ’n Afrigtingsfokus op treëfrekwensie (nadat optimale treëlengte bewerkstellig is) was die sleutel vir die T13-atleet (visueel gestremd) en ’n afrigtingsfokus op treëfrekwensie was die sleutel tot vinniger naellope vir beide die T37- en T38-atlete (serebrale gestremdheid). Alhoewel al die atlete die ritmiese oefenprogram geniet het, het slegs die mees onervare atleet (T38) aangedui dat hy met hierdie vorm van oefening sou wou aanhou.

Sleutelwoorde: Naelloopkinematika; Naelloopbiomeganika; Paralimpiese naellope.

This thesis is dedicated to my parents
for their love, endless support
and encouragement.

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Through my university journey, one thing has become clear – I could never have done any of this, particularly the research and writing that went into this dissertation, without the support and encouragement of a lot of important and special people.

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Chapter One

Setting the Problem

The sprint action requires fast reaction time, good acceleration and an efficient running style (Carr, 1991). In modern athletics, top level competitors sprint all distances from 100m to 400m. Although running may be regarded as a fundamental locomotor skill, sprinting requires long hours of practice and substantial levels of fitness in order to master the skill technique. As sport for athletes with disabilities has progressively entered the public consciousness the growth in the stature and popularity of the Paralympic movement has produced new pressures on these athletes and their coaches to achieve top levels of athletic performance (Bergeron, 1999).

Although the disabilities of athletes in Paralympic sport operate as constraints on their performances, their engagement in serious training and rigorous competition schedules have led to the development of high levels of athletic performance. In the sprinting events specifically, a comparison between the times of Olympic athletes and those of Paralympic athletes illustrates the small gap that exists between them. A comparison of World Record times to the times to the four participants in this study is presented in Table 1.

Table 1

A comparison of World records and the times of the athletes in this study.

	Class	100m	200m	400m
Able-bodied World Record (Men)	**X**	**9.58s**	**19.19s**	**43.18s**
Below Knee Amputee World Record (Men)	T44	10.77s	22.49s	50.61s
Participant 1 in this study	T44	11.8s	22.49s	X
Cerebral Palsy World Record (Men)	T37	11.51s	23.10s	47.88s
Participant 3 in this study	T37	11.51s	23.10s	X
Cerebral Palsy World Record (Men)	T38	10.79s	21.98s	49.33s
Participant 4 in this study	T38	X	X	52.67s
Able-bodied World Record (Women)	**X**	**10.49s**	**21.34s**	**47.60s**
Visual Impairment World Record (Women)	T13	12.28s	24.45s	54.46s
Participant 2 in this study	T13	12.41s	X	X

One consideration in coaching disability sprinting is coaching methods. Coaches of elite level Paralympic athletes follow similar training methods to those they employ to develop their other elite sprinters. According to Bhambhani and Higgs (2011) there is no evidence to either support or refute this approach. The methods appear to be effective if one looks at the sprint times achieved in the Paralympics, but coaches are always looking for optimal ways to train their Paralympic athletes. While recent studies have shown that athletes with physical disabilities pass through the same stages of Long-Term Athlete Development (LTAD) as their able-bodied peers, there is still considerable uncertainty among coaches about the best ways of training athletes in order to help them achieve their full potential (Bhambhani & Higgs, 2011). This uncertainty is coupled with a lack of understanding about how the intense training of these athletes might be associated with an elevated risk for injury.

A second consideration in coaching disability sprinting is variability in performance. According to Beckman (2010), most coaches think of key performance indicators in sprinting to be stride length, stride frequency and body position in relation to the different phases of the sprint (*e.g.* the start, the initial acceleration and the maximal acceleration phases). Coaches tend to look for stereotypes (invariant models or templates) for observing sprint performance and providing corrective feedback to athletes. They may even attempt to eliminate variance between the trials. However, as Thompson, Bezodis and Jones (2009) noted, optimal variance is critical for adaptability in performance. The capacity to make small adjustments to track surfaces, wind, weather, crowd involvement, etc., is a characteristic of highly skilled sprinters, whether able-bodied or disabled. The expected variance in performance in disability sprinting also may be related to their disability. Ferrara, Buckley, McCann, Limbird, Powell and Robl (1992) reported that most athletes with physical disabilities present with some unique kinematic characteristics that not only impact on their performance. They noted that these characteristics could be manifested in variables such as range of motion in one or more joints, muscle strength, postural balance and the quality of sensory information available for motor control. Increases in muscle tone and hyper-reflexia were also found to contribute to altered kinematics and impaired sport technique for athletes in some disability groups.

Purpose of the Study

The purpose of this study was to gain insight into the sprinting of elite athletes with disabilities in order to expand coaches' knowledge of the variability that can be expected in the biomechanics of their start and their sprint kinematics. Coaches should be encouraged to accept that variability is to be expected in addition to consistency – the challenge is to find "optimal" variability.

The sprint performances of four Paralympic athletes representing the amputee, cerebral palsy and visually impaired classifications were analysed, with specific regard to variability in their set positions in the starting blocks and in selected kinematics (stride length and frequency) during the initial acceleration and maximal running phases of their sprint. An additional exploration was made of the potential of a new method of rhythm training (Interactive Metronome™) on selected kinematics of the initial acceleration and maximal acceleration phases of their sprints.

Research Questions

The following research questions with sub-questions were developed to guide this study in relation to four participants:

1. An athlete with a single below knee amputation (Class T43)
2. An athlete with a visual impairment (Class T13)
3. An athlete with cerebral palsy (Class T37)
4. An athlete with cerebral palsy (Class T38).

Research Questions One: What variability can be observed in the sprinting kinematics of Paralympic sprinters?

a) What variability can be observed in the biomechanical features of the set position of the sprint start of a Paralympic athlete over the course of a training year?

b) What variability can be observed in stride length and stride frequency during the initial acceleration phase over the course of a training year?

c) What variability can be observed in stride length and stride frequency during the maximal running velocity phase over the course of a training year?

Research Question Two: Does a rhythm training programme have the potential to influence the sprinting performance of a Paralympic athlete?

a) During the initial acceleration phase.

b) During the maximal running velocity phase.

Methodology

A mixed method case study approach was used in this study in which the sprinting performances of four elite Paralympic sprinters were measured four times over their training year. Variability in the biomechanical features of the 'set' position and in their stride length and stride frequency was determined by comparing their performances recorded at each test session and quantified using the Dartfish movement analysis system. Descriptive presentation of the variances in quantitative data was then reported and interpreted on an individual case-by-case basis. The rhythm training intervention programme was implemented between Test Session Three and Test Session Four, and a separate discussion of the possible influence of this programme on the stride length and frequency of each athlete is also presented.

Significance of the Study

Substantial research has been completed focused on the identification of the optimal kinematic patterns for sprinting in order to present coaches with a relatively invariant biomechanical model to guide their training of athlete (Coh & Tomazin, 2006). However, in order to accomplish the coordination needed for a successful start from the blocks leading into the initial strides, Bradshaw, Maulder and Keogh (2007) determined that a flexible motor control strategy was preferable to an invariant one. They were adamant that a flexible strategy allowed the sprinter to adjust for a variety of performance constraints, such as fatigue, self-confidence, track surface and wind. These authors also associated low joint coordination variability (the adherence to an invariant biomechanical model) with increased injury rates because the same tissues were continually being loaded in exactly the same way, over and over again. They concluded that by developing optimal joint coordination variability, sprinters could improve the consistency of their performance under various conditions as well as reduce the risks of overuse injuries.

Variability in coordination patterns is not just a concern for able-bodied sprinters. The search for a invariant model of sprinting, even for athletes in a specific disability class, is inappropriate. Rather, information is needed regarding how much variability is optimal. This study will contribute to coaches understanding of variability by looking at the set position of elite Paralympic sprinters from three different disability types. Furthermore, analysis of these athlete's movements will contribute to the understanding of sports performance in athletes with a disability and how it may be used as an evidence-based tool to support coaching.

The analysis of selected kinematic variables in this study will also provide information about the effects of a new rhythm programme that has been previousl used to influence the coordination of persons with movement disabilities: The Interactive Metronome™ (IM). The IM™ combines hand and foot tasks with an auditory guidance system to produce a sequence of tasks in which the athletes attempts to precisely synchronise his/her performance to auditory signals. Feedback is provided on the timing accuracy to provide corrective information that will either reinforce or promote adjustments in the timing of performance on subsequent tasks (Interactive Metronome, 2007).

Numerous studies specifically looking at the effect of the IM™ system have been conducted. While a number of these studies looked at the effect of the IM™ system on academic (Taub, McGrew & Keith, 2007; Bartscherer & Dole, 2005; Cason, 2003) or language skills (Sabado & Fuller, 2008; Jones, 2004), however other studies have looked more specifically at the effect of the IM™ system on the control of various motor skills. Shaffer, Jacokes, Cassily, Greenspan, Tuchman and Stemmer (2001) examined the effects of metronome-based coordination training on the motor skill performance of children with attention deficit hyperactivity disorder (ADHD) and found that both balance and bilateral coordination improved significantly following the IM™ training.

Looking specifically at the effects of IM™ training on sport performance, Libkuman, Otanj and Steger (2002) found that IM™ training significantly improved accuracy in golf. These results were later confirmed by Sommer and Rönnqvist (2009). These findings suggest that the IM™ system could have a positive effect on the timing and accuracy of movement. No studies looking at the effect of the IM system in athletics or with elite athletes with physical disabilities could be found. However, a few studies have demonstrated the effectiveness of rhythm-based training on individuals with disabilities. Kwak (2007) found that children with cerebral palsy were able to realise improvements in their movement coordination following their participation in rhythm-based training programme. In a study by Kersten (1981) on the effects of music therapy on visually impaired children, he found that music therapy can assist in minimising many physical problems normally experience by visually impaired children. This emerging pattern of positive impact on some disability groups and in some sports presented IM training as an option when seeking coordination intervention methods for athletes with selected physical disabilities.

Limitations

The following limitations must be acknowledged and remembered when discussion this study:

1. The study includes only four elite Paralympic sprinters from three different disability groups. These athletes do provide a range of constraints and challenges for sprinting performance:

   The single below knee amputee sprinter must accommodate his prostheses into his running gait. This presents a challenge to coordination and a potential disruption to his running rhythm.

The two sprinters with cerebral palsy have an impairment that is located in their central nervous systems that challenges their coordination and may influence their balance as well as their ability to maintain rhythmic running pattern.

The sprinter with a visual impairment experiences limitations to her sensory-perceptual capacity. These limitations may have a negative impact on her balance control and locomotor speed regulation, both of which could disrupt coordination and a steady rhythm in sprinting.

2. This study utilised cameras and Dartfish movement analysis system that are less precise than the more sophisticated systems often used for research purposes. This potential limitation was intentional because the investigator wanted to use technology readily available for coaches in order to encourage them to find ways to use digital data to support their coaching in the field. Forssard (2012) endorsed this type of approach and noted that there is “cultural shift” within some sport science groups take advantage of emerging user-friendly instrumentation to promote communication with coaches in the field.

   During the process of performance analysis, digitising limitations were noted. The recordings were done with two cameras on one side of the sprinter and therefore no information could be gathered from the limbs on the opposite side.

3. Because this study is intended to inform disability athletics coaching, two descriptive models of sprinting were chosen from which the sprint kinematics measured in this study were selected. These features of the sprint are the variables that coaches can most easily see and measure, which makes their selection practical from their point of view. However, as Miller (2011) has noted, the simplicity of these models also limits their scientific capabilities.They are mechanical models that represent some of the critical features of sprinting. According to Hamill and Knutzen (2003) the following variables have been identified by athletic coaches as crucial sprint performance indicators:

Time.

Stride length.

Stride frequency.

Speed.

Inclusion and Exclusion Criteria

The following inclusion criteria shaped this research:

1. Participants had to be volunteers from a single training group of elite sprinters with physical disabilities, and have an IPC classification for sprinting events.

2. Participants had to officially recorded sprint times in IPC competition in 100m, 200m and/or 400m events during 2008 and 2009 that met the standard for entry into international competition in their disability class.

The following exclusion criteria shaped this research:

1. Subjects who had a pre-study injury or who sustained an injury during the study that had a disrupting impact on their sprint mechanics.

2. Subjects who were taking or had taken any substance that may have influenced their sprinting performance.

3. Subjects with physical disabilities who missed more than one week of the training programme implemented in this study.

Terminology

Amputation

An amputation is the loss of a body extremity by trauma, prolonged constriction and surgery. As a surgical measure, it is used to control pain or a disease process in the affected limb, such as malignancy or gangrene (Marsden, 1977).

Cerebral Palsy

Cerebral palsy is an inclusive term which refers to a set of neurological conditions that affect the brain and nervous system and are manifested as a motor impairment. The word palsy means complete or partial muscle paralysis. The more severe forms of cerebral palsy are frequently accompanied by some loss of sensation and uncontrollable body movements or tremors (Berker & Yalçin, 2010; Pakula & Van Naarden Braun, 2009).

Visual Impairment

Freeman, Munoz, Rubin and West (2007) described a visual impairment as a functional limitation of one or both of the eyes or in the visual system due to a disorder or disease. Visual impairments are usually manifested as reduced visual acuity, contrasts sensitivity, visual field loss, photophobia, diplopia, visual distortion, visual perceptual difficulties, or any combination of the above.

Summary

The study was focused on expanding coaches' knowledge base training Paralympic sprinters. Two specific aspects were identified: variability in the biomechanical features of the set position and changes in selected kinematic parameters during the initial acceleration phase and the maximal acceleration phase over four test periods. An additional interest was to investigate the effects of a rhythm training programme on selected kinematics, which was delivered as an intervention between test period three and test period four.

Chapter Two

Review of Literature

This chapter is divided into three main sections. The first section presents the models of sprint performance for phases of the 100m sprint that are used by coaches, followed by a description of the types of training methods commonly implemented to improve acceleration and speed. The second section provides a brief discussion of motor control in relation to sprinting and the role of rhythm and rhythm training. The third section provides insight into the three types of physical disabilities that characterised the athletes who participated in this study.

The Sprint

In modern athletics, top level competitors sprint all distances from 100m to 400m. Although running may be regarded as a fundamental locomotor skill, sprinting requires long hours of practice and substantial levels of fitness in order to master the skill technique. The sprinting action requires fast reaction time, exceptional acceleration and an efficient running style (Carr, 1991). In order to study sprinting in a systematic way, Mann and Sprague (1983) divided the 100m sprint event into three phases (Figure 1):

1. Acceleration phase.
2. Maximal running velocity phase.
3. Deceleration phase.

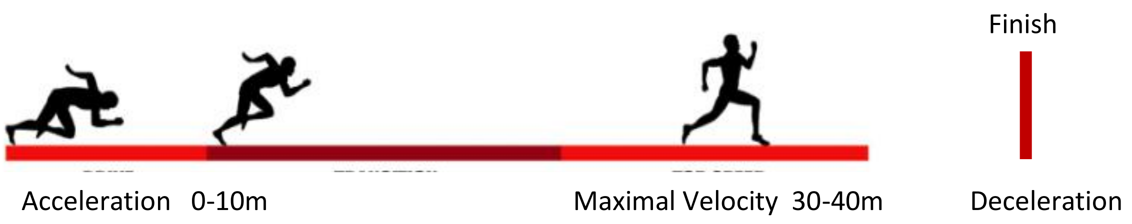


*Figure 1.*The three phases of the 100m sprint

Speed is an integral part of all athletics events and can be expressed as any one of the following: maximum speed, elastic strength (power) and speed endurance (MacKenzie, 2013). Locomotor speed specifically relies on the quickness of movement of the limbs. Although athletes whose muscle fibres are predominantly fast-twitch have a high potential for speed of movement, training is essential for the development of sprinting speed. During the more intense phases of the periodised training year, coaches encourage sprinters to train at 95-100% effort. Hansen (2011) suggested that this level of training promotes maximal activation and recruitment of the fast twitch muscle fibres that allow their limbs to accelerate quickly. This achievement of speed requires the precise and stable coordination of muscle activation patterns.

It has been stated that all runners have a maximum sprinting speed that they cannot exceed (Miller, Umberger & Caldwell, 2010). Both stride length and stride frequency increase as athlete's progress from a slow jog to a maximum sprint. Stride length usually plateaus at an optimal distance for an athlete and stride frequency continues to increase until maximum speed is reached (Luhtanen & Komi, 1978). Greater stride frequencies require the legs to move through the stride cycle at faster rates, and the muscles to shorten and lengthen more rapidly (Miller *et al.*, 2010).

In MacKenzie's (2013) summary of the physiological basis for sprinting, he explained that energy for speed is generated through the anaerobic energy pathway. During the acceleration phase, the sprinter attempts to initiate movement through rapid and powerful movements of arms and legs. The anaerobic energy system is challenged as the sprinter approaches top speed in the maximum running velocity phase (between 30 and 60 metres). This speed component of anaerobic metabolism lasts for approximately eight seconds and should be trained when no muscle fatigue is present (usually after 24 to 36 hours of rest). Sprinters try to sustain velocity through to the finish line at which time they then decelerate.

Although Mann and Herman (1985) concluded that the maximal running velocity phase was the best indicator of sprint success in the 100m event, the body and its segments must be moved as rapidly as possible throughout the entire race (Novacheck, 1998). For example, in order to create and sustain speed, elite sprinters use the forefoot for initial contact with the ground. The hind part of the foot might never contact the ground. In order to gain an insight into the kinematics of the sprint, the two acceleration phases and the maximal running phase of the sprint will be described in the following sections.

The Acceleration Phase: The Sprint Start

The sprint start is a complex motor stereotype requiring a high degree of integration among central movement regulation processing and a sprinter's biomotor abilities (Čoh, Paharee, Bačić & Kampmiller, 2009). A sprint race is started by a starter who issues three commands, On your mark, Set and Go (or some sort of auditory signal is given). On hearing the first command, "On your mark", the athlete will move forward and adopt a position with the hands approximately shoulder width apart and just behind the starting line. The feet are still in contact with the start blocks and the rear leg knee is in contact with the track. When the Set command is heard, the athlete raises the rear leg knee off the ground which will then elevate the hips and shift the centre of gravity up and forward. This position is known as the Set position. Finally, on the command Go or when the a auditory signal is given, the athlete will lift their hands from the track and begin to swing their arms forcefully and drive off the blocks with both legs and power themselves into the first running stride (Brown, Kenwell, Maraj & Collins, 2008).

Under the rules of the International Amateur Athletics Federation (IAAF) all runners/sprinters in races from 100m up to 400m must start from a crouched position in blocks (Novacheck, 1998). This means that the crouched start is a motor skill that must be learned by all sprinters. Magill (2001) defined a motor skill as a voluntary action that has a goal. Specifically, the sprint start is categorized as a discrete motor skill (Magill, 1993). It is considered a discrete skill because it has a definite beginning and it "ends" when the runner achieves an upright normal sprint stride position. Because it is performed so quickly, it is considered to be under open-loop motor control (there is no time to use feedback to make corrections during the explosive movement out of the blocks).

The crouched start puts a sprinter in position to move the centre of gravity rapidly well ahead of the feet, which means that the runner must accelerate very quickly or else fall (Adrian & Cooper, 1995). Figure 2 presents stride-for-stride breakdown of the first two strides out of the blocks.

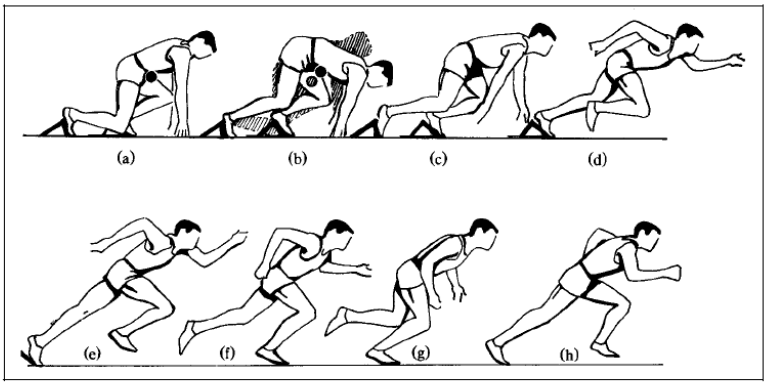


*Figure 2.*The first two strides out of the starting blocks (Hay, 1978:389)

Hay and Reid (1988) developed a model to identify the relationship among the critical kinematic variables in the sprint start (Figure 3).

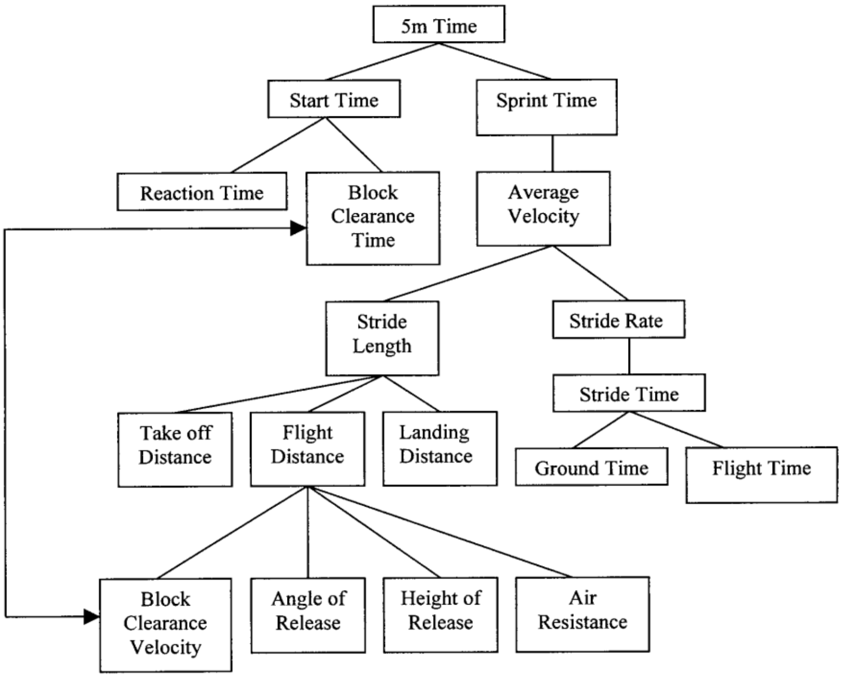


*Figure 3.*Hay and Reid's (1988) model of kinematic variables of the sprint start (0-5m)

Although the crouched start is technically a different skill from actual sprinting, it is an integral part of all sprint events. Stampf (1957) commented that "The important thing is to reach top speed as quickly and smoothly as possible, and this can only be done if the rhythm of the stride begins actually in the starting blocks" (p. 53-54). The purpose of the sprint start is to facilitate an efficient displacement of the athlete in the direction of the run. If executed properly, the sprint start allows the athlete to leave the blocks on balance and with maximum velocity (Brown *et al*., 2008). In order to accomplish this, the following objectives of the sprint start must be achieved:

1. A balanced position in the blocks.
2. A body position where the centre of gravity is as high as is practical and slightly forward of the base of support.
3. The application of force against the blocks in a line through the ankle, knee and hip joints, the centre of the trunk and head.
4. The application of this force against the blocks and through the body at an angle of approximately 45°.
5. Optimum knee joint angles in both the front and rear leg.
6. Clearance of the blocks on balance and with the greatest possible velocity.

Acceleration out of the blocks (block acceleration) is a complex cyclical movement. Block acceleration is that phase of the sprint where the kinematic parameters of the sprint step change most dynamically (Čoh, Tomažin & Štuhec, 2006). Locatelli and Arsac (1995) identified the following three interdependent parameters that determine the sprint start, all of which Mero, Komi and Gregor (1992) concluded are controlled by central movement regulation processes:

1. The change in the frequency and length of stride.
2. The duration of the contact and flight phases of each stride.
3. The position of the centre of gravity at the moment of foot contact with the ground.

Stride frequency and stride length are the most common kinematic variables discussed in relation to changes in sprint performance. Stride frequency is presumed to be under central motor control and each individual is believed to have a preferred tempo that may be genetically predetermined (Mero, Komi & Gregor, 1992). A faster rate of stride frequency (tempo) is associated with a shorter the stride length and a slower rate (tempo) is associated with a longer stride length. The efficiency of block acceleration is defined as an optimal ratio between the length and frequency of the athlete's strides (Čoh *et al*., 2006).

Luhtanen and Komi (1980) divided the contact phase of the sprint step in block acceleration into a braking phase and a propulsion phase. These two parts together made up the total ground contact time. Execution of the contact phase is one of the most important factors in sprint velocity efficiency (Čoh *et al*., 2006). This phase must be as short in duration as possible with an optimal ratio established between the braking phase and the propulsion phase. It also must be remembered that the relationship between the ground contact and the flight phases of each stride changes during the sprint. This is because the total ground contact times decrease and flight phases increase (Čoh *et al*., 2009).

In a study conducted by Čoh *et al.* (2006), it was found that there was a strong correlation between the efficiency of the start and subsequent block acceleration. According to their research, an optimal set position can make a significant contribution to the maximal block velocity of the sprinter. The transition from block velocity to block acceleration depends on the execution of the first step, particularly the length of the step and positioning of the foot in the braking phase. The efficiency of block acceleration generates the time aspect of the contact/flight index in the first ten steps. Stride length and frequency have to be coordinated to such an extent as to enable ground contact times to equal those of the flight phases within the shortest time possible. In the first three steps, the body's centre of gravity has to rise gradually in a vertical direction in maximise the horizontal component of block velocity.

The Acceleration Phase: The Sprint Stride

There are two main phases of the running stride: the supporting and the non-supporting phases of each limb. The supporting phase consists of breaking, amortization and propulsion and the non-supporting phase (floating or flight) consists of rising and falling (Kharb, Saini, Jain & Dhiman, 2011).

Kharb *et al*. (2011) noted that as one moves from walking to running there is an increase in the swing phase of the leg and decrease in the stance and double support phases as the speed of movement increases. The final transition from walking to running happens when the double support phase completely disappears. During running, four distinct sub-phases have been identified (Lohman, Sackiriyas & Swen, 2011) (Figure 4):

1. Stance sub-phase.
2. Early swing or float sub-phase.
3. Middle swing sub-phase.
4. Late swing or float sub-phase.

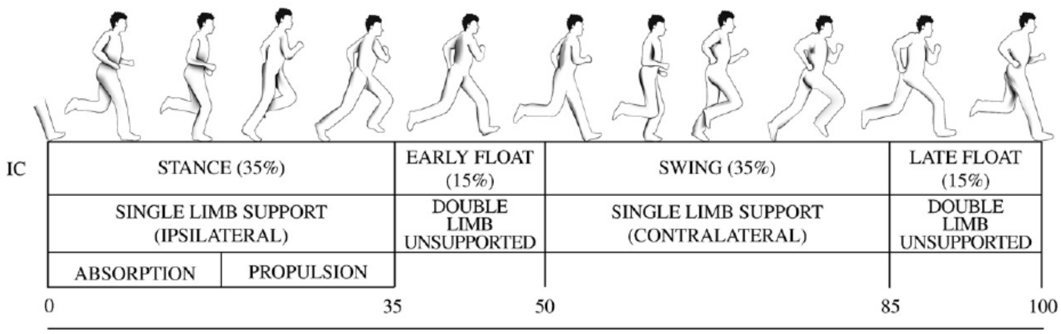


Figure 4. The phases of the running stride (Lohman, Sackiriyas & Swen, 2011:152)

The ideal sprint technique would be to complete lower-leg extension in sufficient time during a float sub-phase in order to produce a significant amount of lower-leg flexion speed at touchdown (Hay, 1978). This would result in a reduction in the forward breaking force during the initial ground contact which would have a positive influence on stride length and the velocity of running (Mann & Herman, 1985). As the body passes over the rigid grounded leg (amortization) the ground reaction forces add horizontal drive to the forward-moving body (propulsion). Energy stored during the eccentric portion of amortization can be utilised during the following take off phase.

Mann and Herman (1985) defined take-off as the active extension of both the hip and the ankle of the grounded leg to launch the athlete into a flying trajectory with a small angle (2-3 degrees). This low trajectory minimises the height of the centre of gravity because too high centre of gravity during the flight sub-phase will lead to excessive breaking forces at ground contact during the next stride. After leaving the ground, the athlete actively prepares for a dynamic landing (Hay, 1978).

Knee flexors should hold the swing leg in a flexed position (30^0at the knee) during the entire supporting leg amortization in order to increase the speed with which this limb can be cycled to the front position (Hay, 1978). Moving forward and downward, the swinging leg's momentum increases force applied over the supporting leg. As it passes the vertical, the swinging leg starts to move forward and upward. Its ballistic momentum assists in the forward acceleration of the moving body's centre of gravity. To control these actions through the propulsion sub-phase, the athlete should bring the foot of the flexed leg through at the same level as the supporting knee, triggering this action with dorsi-flexion of the swing leg ankle. The athlete's centre of gravity should not reach a vertical displacement of greater than 6cm during each flight sub-phase, as this will increase the supporting phase contact time. Longer supporting phase contact time leads to a decrease in the rate of the leg turnover (stride frequency) and ultimately a decrease in stride length. Sprint acceleration is constrained by the relative duration of the support phase, and too much time spent in amortization will decrease stride frequency and stride length resulting in a slower horizontal velocity (Mann & Herman, 1985).

The Maximal Running Velocity Phase: The Optimal Sprint

Hay (1978) identified the critical kinematic variables that affect the optimal sprint when running at or near maximal velocity (Figure 5). These variables are not identical to those that affect the initial acceleration of the sprint. Too long a stride length (over-striding) may decrease stride frequency while too rapid a stride frequency may shorten stride length. Both of these conditions can decrease sprinting speed (Kunz & Kaufmann, 1981).

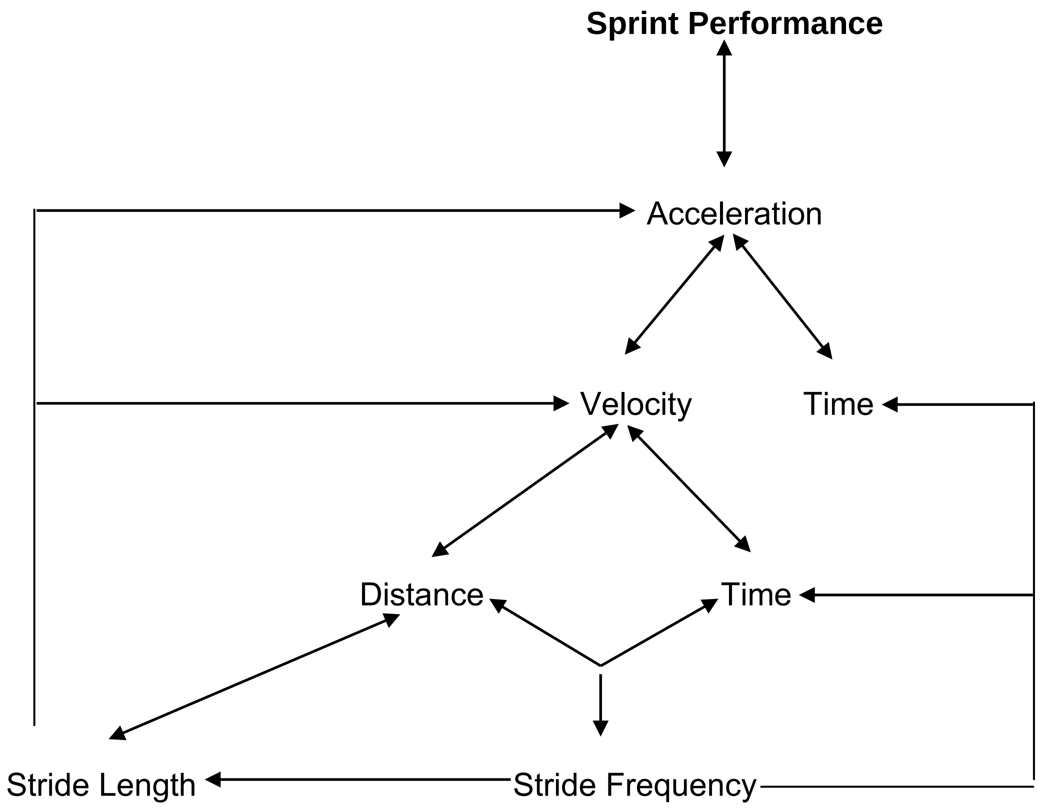


Figure 5. The kinematic variables of sprinting during the maximal acceleration phase of the sprint (Hay, 1993)

According to Mero, Komi, Rusko and Hirvonen (1987), stride frequency is more critical for achieving maximal sprinting performance than stride length. They also stated that optimal values for stride length and stride frequency exist for each sprinter. The optimal relationship between these factors for an individual sprinter would depend up standing height, leg length, crural index (the ratio of thigh length to leg length), explosiveness of muscular contractions and speed of movement of the limbs (Kunz & Kaufmann, 1981). Murphy, Lockie and Coutts (2003) supported the critical role of stride frequency in sprint performance, finding that stride frequency had a significant effect on early acceleration while stride length did not.

There was some contradiction in the research about the roles of stride frequency and stride length. When Mackala (2007) examined the contribution of stride frequency and stride length to the velocity curve of the 100m sprint, he found that stride length was significant and stride frequency was not. During his study both amateur and elite sprinters were included. From his analysis he concluded that stride frequency is not the most important factor determining performance and that stride length is a far better performance-determinant over 100m.

In most circumstances, both stride frequency and stride length increase with increasing speed (Hoshikawa, Matsui & Miyashita, 1973). Yokoi, Shibukawa and Hashihara (1987) studied two groups of differing stature (average leg length difference of 7cm) and similar running velocities (9.30 m/s longer-legged group to 9.36 m/s for the shorter-legged group). Not surprisingly, they found that the longer-legged athletes had a longer average stride length when compared to the shorter-legged group as well as a much slower average stride rate.

As running speed increases, an athlete spends proportionately more time in leg recovery than in leg support, suggesting that leg recovery is another important factor in sprint running (Wood, 1987). At maximal running speed an athlete aims to spend as little time on the ground as possible. Mann and Herman (1985) analysed the performances of Olympic medallists in the 200m and found a significant decrease in support time as sprint performances became faster. They also found that the major difference between first and second place finishers was their average stride frequency. This result supported earlier research by Mehrikadze and Tabatschnik (1982) who found that differences in stride frequency were the source of significant differences in the performances of elite sprinters.

Hoffman (1971) stated that stride length and leg length both correlated positively with running velocity. Plamondon and Roy (1984) explored relationships between stride frequency, stride length and maximal running velocity. They suggested that there are two specific factors that account for 90% of the variance in running velocity. The first factor was related to the breaking phase component of the support phase (distance the foot is placed forward of the centre of gravity and foot velocity at ground contact). The second factor was the duration of the support phase. Sprint acceleration was especially sensitive to the relative duration of the support phase (Fletcher, 2009). Mann and Herman (1985) found a significant decrease in support time as sprinting performance improved.

In terms of kinematic variables, Mann and Herman (1985) stated that the greatest factor dictating success in sprinting is the maximum horizontal velocity.

However, Moravec, Ruzicka, Susanka, Dostal, Kodejs and Nosek (1988) contended that a high maximum running velocity is not a guarantee of final sprint time. In their study, several athletes reached a maximum running velocity of greater than 11.0 m/s but were not able to better 10.50 seconds over a 100m distance.

Deceleration Phase

The final 10 - 20m of a sprint typically constitutes the deceleration phase of the sprint. However, varying rates of fatigue among athletes means that this can fluctuate in length. Both muscle fatigue and especially fatigue of the central nervous system lead to a decreased stride frequency for which some sprinters attempts to compensate by increasing their stride length. Some sprinters appear to get faster at the end of a race which is only an illusion resulting from their compensation for varying rates of fatigue. However, in recent years it has been noticed that the maximum speed of top athletes can be maintained with minor fluctuations until the finish (IAAF, 2002). This recent shift to a shortening of the deceleration phase could be attributed to the training methods used by coaches to improve acceleration and speed and speed endurance.

Methods to Improve Acceleration and Speed

Young (2011) described sprinting as a complex motor skill characterised by a high neuromuscular demand. He simplified the concept of sprint speed to a product of the interaction of stride length with stride frequency. He also identified the following five focus areas to take into account in designing training methods to improve acceleration and speed in sprinting:

1. Environmental factors (*e.g*. surface).
2. Physical attributes (*e.g.* strength and power).
3. Dynamic mobility (e.g. flexibility).
4. Mechanical aspects (*e.g.* skill technique).
5. Neuromuscular efficiency (*e.g.* coordination).

Environmental Factors

It has been acknowledged for some time that training and competition stress is often intensified by the environmental factors which can accelerate the onset of fatigue (Edwards, Harris, Hultman, Kaijser, Koh & Nordesjo, 1972). These factors can range from the heat of the day to the surface on which the athletes compete.

Training and practice should include performances under a variety of climatic conditions. During extremely hot conditions there is competition within the body for cardiac output, with the demand for increased circulation and heat dissipation in addition to the metabolic requirements of exercising muscles (MacDougal, Reddan, Layton & Dempsey, 1974). Maxwell, Aitchison and Nimmo (1996) studied the detrimental effects of climatic heat stress on the performance of intermittent high intensity running. In their study it was found that the participants could exercise supramaximally in a hot, humid environment and that the deterioration of their running performance in that environment was alleviated when the sprint took place in a cooler environment.

A further environmental factor worth study is the training surface, which if carefully selected could make a positive contribution to conditioning. Because ground contact is critical for the generation of force for sprinting, variations in training surfaces have been considered when training for speed. A study by Alcaraz, Palao, Elvira and Linthorne (2011) looked at the effects of a sand running surface on the kinematics of sprinting at maximal velocity. They compared the kinematics of sprinting at maximum velocity on a dry sand surface to the kinematics of sprinting on a tartan athletics track. They concluded that sprinting on a dry sand surface may not be an appropriate method for training the maximum velocity phase in sprinting. Although running on sand did exert a substantial overload which held the promise of improved strength, it also induced detrimental changes to the athlete’s running technique which could have a negative transfer to sprinting technique during competition.

Physical Attributes

Strength is fundamental for successful sprinting. The conventional approach to the development of strength is weight training. Dare and Kearney (1988) identified these classic benefits associated with strength training:

- A total body conditioning which will aid in preventing muscle imbalances and assist in providing a general muscle-tendon-ligament strengthening, which can result in a reduction of injury risk to the athlete.
- An increase muscle group strength, through either increased recruitment of muscle fibres or strengthening of muscle fibres, which can results in an increase in the athlete's ability to apply power to the ground.

In a study conducted by Mikkola, Vesterinen, Taipale, Capostagno, Hakkinen and Nummela (2011), the effects of heavy resistance, explosive resistance and muscle endurance training on high-intensity running performance were studied. The subjects were recreational endurance runners. They found that all three modes of strength training used concurrently with endurance training were effective in improving treadmill running endurance performance. Both heavy strength training and explosive strength training were found to be beneficial in improving neuromuscular characteristics. Heavy resistance training in particular contributed to improvements in high-intensity running. They concluded that endurance runners should include heavy resistance training in their training programmes to enhance endurance performance, such as improving sprinting ability at the end of a race.

Speed endurance training has been examined. Dare and Kearney (1988) defined speed endurance for sprinters as the ability to maintain high sprinting speed for a sustained period of time. Speed endurance is the capacity of athletes to perform at a fast rate for a sustained period of time (Shaver, 2008). Speed endurance training exercises consist of bouts of relatively short duration at near maximal intensities (Iaia & Bangasbo, 2010). Although the workouts recommended for the development of speed endurance vary according to the cycle in the training year, 100/200m sprinters will typically do repetitions of 100-

300m, with volumes of 2-10 repetitions. Sprinters at the 200/400m distances typically do repetitions of 150-600m, with volumes of 2-12 repetitions.

Other research has investigated the effect of different training methods on other physical attributes. Vick and Gervais (2005) found that training on a resisted sprint ergometer had a significant effect on running speed and acceleration. Myer, Ford, Brent, Divine and Hewett (2007) studied the effects of resistive ground-based speed training and incline treadmill speed training on speed related kinematic measures and sprint start speed. In their results they found that both incline treadmill and resistive ground-based training were effective at improving sprint start speed.

Dynamic Mobility

Dynamic mobility warm-up exercises are not only essential for safe workouts but also contribute to speed and acceleration. These kinds of exercises aim to increase joint mobility, elevate the heart rate and activate important muscles prior to participation in either a training or skill session. Maintaining a regular dynamic mobility programme is one of the least strenuous methods that can support the development of sprinting speed (Hansen, 2011). As sprinters become more accustomed to applying force over the increased range of motion, they may be able to generate more force over each sprinting stride (MacKenzie, 2013).

Flexibility programmes can contribute to dynamic mobility if they work with full ranges of joint motion. According to MacKenzie (2013) a flexibility programme consists of two components. First, the programme should include passive stretching outside of the athlete’s regular training session (*e.g*. stretching at least once a day). Second, the programme should focus on exercises that develop dynamic flexibility during the athlete’s warm-up and workout routines. These exercise should enhance the elastic properties of the muscles and connective tissues which will contribute to the prevention of injuries during high-speed activities (Hansen, 2011).

A less conventional approach to warm up and increasing flexibility is whole-body vibration. Research by Delecluse, Roelants and Verschueren (2003) found that following a warm-session on a whole-body vibration platform, athletes had increased strength in their knee extensors. These findings were later supported in a study by Paradisis and Zacharogiannis (2007), where athletes participated in a six-week whole-body vibration training programme that was found to have a significant effect on improving sprint performance, attributed to a longer stride length. The findings of these studies are in contrast to the results by Bullock, Martin, Ross, Rosemond, Jordan and Marino (2009) who found that athletes had lower sprint velocities following a whole body vibration warm-up. Roberts, Hunter, Hopkins and Feland (2009) found that while whole body vibration appeared to produce greater peak forces during sprint starts, no effects on sprinting speed were found following participation in the vibration training.

Mechanical Aspects

The mechanical aspects of sprinting are high on a coach's list of factors that require attention. Lockie, Murphy and Spinks (2003) looked at the effects of resisted sled towing on sprint kinematics in field-sport athletes. They concluded that when compared to a lighter sled load, a heavier sled load generally resulted in a greater disruption to normal acceleration kinematics. They recommended the use of the lighter sled loads for training programmes in order to minimise this disruption.

Alcaraz, Palao, Elvira and Linthorne (2008) compared the kinematics of sprinting at maximum velocity to the kinematics of sprinting when using three of types of resisted sprint training devices (sled, parachute and weight belt). They found that the three types of resisted sprint training devices were appropriate devices for training the maximum velocity phase in sprinting. These devices exerted a substantial overload on the athlete, as indicated by reductions in stride length and running velocity, but induced only minor changes in the athlete's running technique. When training with resisted sprint training devices, they recommended that the coach should introduce sufficiently high resistance so that the athlete experiences a large training stimulus, but not so high that the device induces substantial changes in sprinting technique.

Alcaraz, Palao and Elvira (2009) continued with this line of research and attempted to determine the optimal load for resisted sprint training with sled towing. In their study, they found that an excessive load in resisted sprint training produced changes in running patterns and identified load control as essential to effective sled towing. Another study by Cronin, Hansen, Kawamori and Mcnai (2008) looking at the effects of weighted vests and sled towing on sprint kinematics found that both sled towing and weighted vest sprinting both resulted in short-term acute changes in sprint kinematics during the acceleration phase of sprinting, but that only the sled pulling showed a long-term effect on sprint.

These results are in contrast to the findings of LeBlanc and Gervais (2004), who found that resisted sprint training devices (sled, parachute and weight belt) had no significant effect on the sprint performance when it these training aids were compared to athletes training without them.

Neuromuscular Efficiency

Neuromuscular Efficiency is the ability to allow agonists, antagonists, synergists, and stabilisers to work together to produce force, to reduce force and to dynamically stabilise the entire movement (Patsika, Kellis & Amiridis, 2011). Plyometric training is often categorised as an approach that is focussed on developing neuromuscular efficiency. Plyometric exercises involve very intense and quick movements designed to increase athletes' ability to apply force to the ground. Because sprinters apply large forces to the ground from small knee angles (less knee bend and less leg flexion throughout the force application) with very short ground contact times, plyometric exercises imitate these actions. Plyometric exercises include bounding, skipping and hopping without a flying start (200-600m of varied activity).

Rimmer and Sleivert (2000) conducted research to determine the effects of an eight-week sprint-specific plyometric programme on sprint performance. They concluded that a sprint-specific programme could improve 40-m sprint performance to the same extent as standard sprint training, possibly by shortening ground contact time. During selected cycles in the training year, plyometric exercise routines are done at least once or twice a week (1 x week fast plyometric activity, 1 x week general plyometric activity).

Research completed by Markovic, Jukic, Milanovic and Metikos (2007) evaluated the effects of sprint training on muscle function and dynamic athletic performance and then compare them with the training effects induced by standard plyometric training. Based on their research, they concluded that short-term sprint training produces similar or even greater training effects in muscle function and athletic performance than conventional plyometric training. In addition, they recommended the use of sprint training as an applicable training method of improving explosive performance of athletes in general. Chelly, Ghenem, Abid, Hermassi, Tabka and Shepard (2010) suggested that coaches implement a biweekly plyometric training programme which includes adapted hurdle and depth jumps.

In order to refine the coordination of sprinting actions, the complex coordination and timing of the motor units and muscles involved in sprinting can be rehearsed at slower speeds as well as practiced at maximum speed (Hansen, 2011). In a typical programme, athletes perform repetitions of short distances (30-100m) done at or near full speed (95-100%). Workouts emphasise “complete” recoveries of 3-4 minutes between repetitions and 5-8 minutes between sets.

The IM™ programme implemented within this study is focused on training the rhythmic abilities of sprinters using the computer-based interactive metronome. In order to look more closely at the rationale behind this approach, a closer look at the motor control processes that underlie sprinting will be presented in the following section.

Motor Control and Sprinting

As advocates of an ecological approach for understanding motor control, Kugler, Kelso and Turvey (1982) proposed that the Dynamic Systems Theory be adopted for explaining motor performance, skill acquisition and the development of pedagogical methods. Within this theory, the individual is regarded as a complex system that functions as the interaction of many sub-systems. These interactions “self-organise” according to a functional goal or intention in a particular environmental context and in relation to a variety of constraints that are relevant in a particular situation (Davids, Button & Bennett, 2008).

Researchers in the motor control and learning of sport skills often follow Newell's model (Figure 6 which identifies three kinds of constraints that influence the organisation of movement performance: Individual constraints, task constraints and environmental constraints (in Haywood & Getchell, 2009).

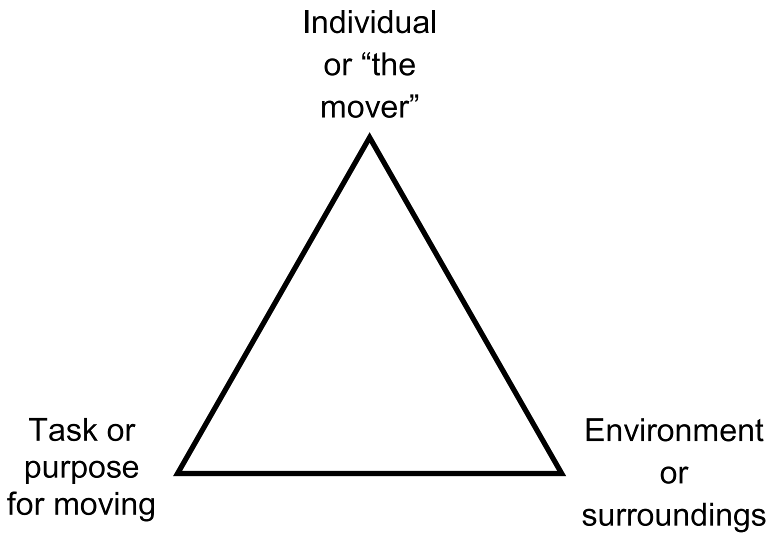


Figure 6. Newell's interpretation of the Kugler *et al.* (1982) model of the constraints that interact to shape motor performance (in Haywood & Getchell, 2009)

Proficiency in this "self-organisation" process has been attributed to the development of fundamental coordinative structures that will allow the individual to adapt their movement patterns to achieve goals within the variety of constraints that impact on the particular situation (Davids *et al.*, 2008; Magill, 2003). Individual constraints, task constraints and environmental constraints have been summarised as follows:

1. Individual Constraints

   Individual constraints are the physical and mental characteristics that are unique to an individual and which will shape their behaviour (Davids *et al.*, 2008; Haywood & Getchell, 2005). These constraints can be placed on a continuum ranging from structural to functional.

(a) Structural Constraints

Structural constraints are related to physical characteristics and variables associated with an individual's physical capacity. These constraints may be unchangeable or enduring. They also may be resistant and slow to change although change can occur over time, especially with maturation (Haywood & Getchell, 2005). Within the scope of this study, amputation, cerebral palsy and visual impairment are all regarded as structural constraints that affect an individual's performance in sprinting.

(b) Functional Constraints

Functional constraints are related to those characteristics and variables associated with adaptability, change and even self-control. These constraints may change frequently and even relatively easily in a short period of time. They include level of expertise, physical fitness, motivation, emotions, memory, and focus of attention, etc. (Davids *et al.*, 2008; Haywood & Getchell, 2005). Within the scope of this study, rhythm is regarded as a functional constraint of sprinting.

2. Environmental Constraints

Environmental constraints represent a broad category of variables that refer to the physical and the socio cultural variables of the surroundings. They are not regarded as task specific because they could potentially affect performance of any task, or at least many tasks, it those surroundings (Davids *et al.*, 2008; Haywood & Getchell, 2005). Variables such as rain, wind and air temperature are often constraints on sprint performance, but in this study, they were controlled and had no impact.

3. Task Constraints

Task constraints are those variables that are specific to the performance context but are external to the individual performer (Davids *et al.*, 2008). The acknowledgement of the sprint as a discrete skill (a defined beginning and end), the length of the sprint distance, and the set-up of the blocks would be examples of task constraints in this study.

From a Dynamic Systems approach, becoming more skilful involves the development of muscle synergies that can be combined to operate as “coordinative structures” to effect motor performance and these coordinative structures can be adapted to achieve a successful interaction among the individual, task and environmental constraints (Goodway & Branta, 2003). Because the focus of this study is on elite level sprinters with disability and the potential effects of rhythm training on their performance, a brief description of the phases of skill development is presented in the next section, followed by three sections more specific to the intervention programme in this study: Coordination, Rhythm as a Control Parameter, and Rhythm Training.

Phases of Skill Development

Stable yet adaptable coordination patterns are considered to be the building blocks of skill acquisition. Stergiou, Jensen, Bates, Scholten and Tzetzis (2001) found that changes from one coordinated motor pattern to a different coordinated pattern occurs when a variable to which the neuromotor system is sensitive is scaled up or down through a critical threshold. This variable is referred to as a control parameter.

Control parameters were described by Shumway-Cook and Woollacott (2002) as those variables that regulate changes in the system in relation to performance of a particular task. Potential control parameters include variables such as force, tempo and speed. Control parameters can be manipulated to influence the stability of the system (Magill, 2003). For example, when a control parameter is changed beyond a certain critical boundary, the coordinative relationships within the system will give way to a new coordinative structure (Phillips & Clark, 1997). This is the case when the speed of walking is raised to the point where the individual begins to run instead.

Chow, Davids, Button and Coh (2008) advocated the use of Newell’s model of three stages of motor learning to understand the progression from novice-to-expert. They linked these stages of motor skill learning to the progressive organisation and reorganisation of coordinative structures in response to changing constraints in movement performance situations. Davids *et al.* (2008) described this process as the development of coordination in which learning and practise lead to strengthened connections among the coordinative structures involved in task goal achievement. As the coordination patterns increase in stability, the individual is more able to adapt to the changing constraints of tasks and environments.

Stage 1: Coordination

In the Coordination stage, the learner establishes basic relationships between the motor system components to achieve the movement goal (Chow *et al.*, 2008). The individual puts together a movement pattern through assembling the relative limbs and trunk movements into the correct sequences in relation to an intention (Davids *et al.*, 2008).

Stage 2: Control

The Control stage is where exploration of the movement pattern under different conditions takes place. Davids *et al.* (2008) stated that the flexible use of coordinative structures is explored through repeated practice under variable conditions. With practice and repetition, more complex muscle synergies are formed that effectively reduce the degrees of freedom, making movement performance easier to manage and regulate (Davids *et al*., 2008; Salman, 2002).

Movement control in this stage involves the assignment of overall parameter values to particular coordinative structures (Chow *et al.*, 2008). The features that are parameterised include variables such as displacement, speed, force, size, amplitude and timing (Jensen, Phillips & Clark, 1994).

Stage 3: Skill

In the Skill stage the performer becomes adaptable in their performance. The optimisation of the control parameters that are linked to the coordinative structures enhances movement efficiency and control of movement patterns. Individuals become capable of flexible and efficient actions and are able to utilise these to provide the optimal solution to movement situations (Davids *et al.*, 2008).

Variability in motor performance is of particular interest for sprinting coaches. While it may seem that a strict automated replication of the sprinting action would be ideal, recent analyses have indicated otherwise. A study by Bradshaw, Maulder and Keogh (2007), for example, clearly demonstrated that among elite sprinters, the optimal motor control strategy is characterised by variability patterns of joint control, although outcome parameters such as stride length and stride frequency are consistent. This is compatible with the Dynamic Systems approach that consistent standards of performance across a variety of conditions rely on flexible joint coordination patterns adapted to suit the demands of the task. To achieve the Skill Phase in motor control, a sprinter must be able to adapt to the conditions they will encounter in competition, including condition of the track, emotional environment, weather conditions, etc.

Coordination

“The essence of coordination is the sequencing, timing and grading of the activation of multiple muscle groups” (Shumway-Cook & Woollacott, 2007, p.115). Muscle activation at the appropriate time and with the correct amount of force produce the smooth, efficient and successful movements associated with coordination. Learning to synergise muscle activation patterns is central to process of motor learning. As an individual becomes more skilful, the sequencing and timing and grading of activation becomes more efficient and successful.

Magill (2003) referred to the development of coordination as the attainment of a stable state. Stable states have been associated in the motor control literature with the term attractor states and they are associated with the preferred coordination patterns of an individual (Davids *et al., 2008*; 2008; Magill, 2003). Shumway-Cook and Woollacott (2007) used a related term - attractor wells - to describe the relative stability of different movement patterns. They explained that the more stable the movement pattern, the deeper the attractor well and the deeper the well, more difficult it is to disrupt coordinated movement with the introduction of perturbations such as environmental changes.

Shumway-Cook and Woollacott (2007) described stable states as “well entrained systems”, referring to the reliability with which coordinated movement could be dynamically organised despite challenging performance circumstances. Well entrained movements would be characterised by the optimal sequencing, timing and grading of muscle activation patterns. Stability and entrainment should not be equated with lack of variability in movement performance. Variability in movement is not only a function of the multiple degrees of freedom that must be constrained in the performance of any skill, but also a characteristic of motor performance. Skilled individuals typically demonstrate optimal levels of variability in the control strategies that enable their motor performance (Muller & Sternad, 2009).

Motor control and timing are linked and the goal of good timing is the optimal synchronisation of synergies (Salman, 2002).The running style of an elite sprinter is an example of a well entrained muscle activation pattern. It could be described as a stable system in which the sequencing, timing and grading of muscle activation associate in as attractor well that is resistant to disruption. Practice activities that focus on optimalising the sequencing, timing and grading of activation during sprint performance would be of interest to coaches and sprinters if engaging in these activities produced an improvement in achieving the ultimate goal of sprinting – speed. One aspect of timing that has been identified as a control parameter for running is the rhythm entrained in the coordination pattern (Miller, 2011).

Rhythm as a Control Parameter

Rhythm was identified as a distinguishing characteristic of skilful performance, and has been acknowledged to be a special type of timing that underlies the acquisition and performance of motor skills (Derri, Tsapalidou, Zachopoulou & Kioumourtzoglou, 2001). According to Mastrokalou and Hatziharistos (2007) rhythmic ability is based on an internal representation of time which affects the way in which movements are performed.

Rhythm has been proposed to operate as a control parameter affecting the relationship of the space and time components of performance which influence the accuracy of movement performance (Ben-Pazi, Kukke & Sanger, 2007). Hansen (2008) highlighted rhythm as a critical parameter in sprint performance. He explained that the optimal combination of stride frequency and stride length must be coordinated precisely during the different phases of a sprint. Inappropriate rhythm at any given phase could result in tightness, over-striding, premature depletion of energy and many other performance limiters.

Athletes who are working to improve their acceleration often either rush their strides too much (overly high stride frequency) or push too hard on their individual stride length, resulting in longer strides with a rhythm that is too slow(Hansen, 2008). In both cases, fluidity of motion is not present and the athletes are working well below their acceleration potential John Jerome (1999) presented a theory in his book *The Sweet Spot in Time: The Search for Athletic Performance*, where he proposed all top athletes had greatly developed their “sweet-spot” for biomechanical movements in their sport – whether it was a golf-swing, baseball pitch or running. Finding that sweet spot for sprinting rhythm is a critical step in the skill development process.

Rhythm Training

The purpose of rhythm training is to practice the synchronised timing of movement patterns in order to improve the coordination of actions (Burpee, DeJean, Frick, Kawar, Koomar & Murphy-Fischer, 2001). Some authors have contended that rhythmic ability is genetically determined and therefore cannot be trained, while other authors have argued that rhythmic ability is trainable and can improve after a rhythmic entrainment programme (Zachopoulou, Derri, Chatzopoulos & Ellinoudis, 2003; Zachopoulou & Mantis, 2001).

Rhythm Training Programmes

Rhythm training programmes usually challenge individuals to synchronise their movements to an external rhythmic stimulus (Zachopoulou *et al.,* 2003). Synchronisation has been improved in some individuals as a result of participation in a training programme (Greenspan & Shanker, 2007). Mastrokalou and

Hatziharistos (2007) suggested that rhythmic ability enhancement programmes had the potential to help improve children's motor coordination. Rhythm training programmes for adults are commonly associated with rehabilitation activities designed to re-establish coordination and with interventions with persons who have impairments that have a negative impact on coordination, *e.g.* cerebral palsy (Shumway-Cook & Woollacott, 2007).

There is some variety in the mode of delivery for external rhythmic stimuli in rhythm training programmes. Zachopoulou *et al.* (2003) implemented a music and movement programme in their research on the rhythmic ability of preschool children (ages 4 to 6). After a 10-week (35 to 40 minute sessions twice a week) intervention programme, there was a significant improvement in the rhythmic ability of the children in the experimental group. They concluded that young children's neuromuscular system could be trained to respond to rhythmic stimuli. They advised that such programmes should contain simple movements and simple rhythms and should involve the activation of large muscle groups.

Haas, Distenfeld and Axen (1986) looked at musical rhythm and breathing. They concluded that music could be used as a kind "pacemaker" for the entrainment of breathing patterns. They also incorporated tapping to a rhythm as a means for reinforcing the rhythmic beat presented through music. Tapping rhythms are typically presented by some kind of metronome as a regular sequence of audible sounds. The rationale for metronome training is that by practicing the synchronisation of movements to a precise rhythm, the individual will improve the ability to assemble their coordinative structures to create movement patterns.

Interactive Metronome Training

This study uses a very specific form of metronome-based rhythm training: The Interactive Metronome™ (IM). The IM™ combines hand and foot tasks with an auditory guidance system to produce an sequence of interactive exercises in which the individual strives to synchronise task performance precisely with auditory signals. Feedback is provided on the timing accuracy of each performance to provide corrective information that will either reinforce or promote adjustments in the timing of performance on subsequent tasks (Interactive Metronome, 2007).

The underlying rationale for IM™ training is that the processes of sequencing and coordinating movement patterns are based on an internal sense of rhythmicity and that this rhythmicity can be improved with practice to a metronome (Koomer, Burpee, DeJean, Frick, Kawar & Fischer, 2000). During IM™ training, the practice environment consists of providing an individual with auditory input (the computerized metronome beat) via headphones. The individual is presented with specific tasks of tapping their hand, or foot, or both in synchrony to the metronome. The computerized guide sounds provide feedback to assist the individual to fine tune their movements to the beat.

Diamond (2003) noted that IM™ training may contribute to more efficient and more consistent neural processing of muscle activation patterns. Myskja (2005) concluded that when movements become more rhythmically stable, a more optimal coordination of movement performance is achieved. This outcome would be advantageous to sprinters who are continuously striving for optimal efficiency and effectiveness in the execution of the coordination patterns that support the different phases of sprint performance (Sommer & Rönnqvist, 2009).

Selected Physical Disabilities

Because the athletes who participated in this study come from only three different groups of disability (amputation, cerebral palsy and visual impairment), the following section will be limited in scope to their disabilities only. A specific focus on sport participation is included and implications for sprint performance are highlighted.

Amputation

An amputation is the loss of a body extremity by trauma, prolonged constriction and surgery. As a surgical measure, it is used to control pain or a disease process in the affected limb, such as malignancy or gangrene (Marsden, 1977). The participant in this study injured his lower leg badly in an accident, resulting in an amputation.

Classification of Amputation

For the purpose of ensuring equity in competition, participants with amputations are assigned a general classification based on how much of extremity is missing and then a sports classification so that they will compete against persons with similar movement abilities. The general classification is as follows (IPC, 2011):

1. AK = Above or through knee joint.
2. BK = Below knee, but through or above talo-crural joint.
3. AE = Above or through elbow joint.
4. BE = Below elbow, but through or above wrist joint.

There are nine classes for amputee sport, each comprised of combinations of the general classes.

The delineation between classes is regulated by the International Wheelchair and Amputee Sports Federation (IWAS) and is as follows (IPC, 2011):

1. Class A1 = Double AK.
2. Class A2 = Single AK.
3. Class A3 = Double BK.
4. Class A4 = Single BK.
5. Class A5 = Double AE.
6. Class A6 = Single AE.
7. Class A7 = Double BE.
8. Class A8 = Single BE.
9. Class A9 = combined lower plus upper limb amputations.

An additional sport-specific classification is then provided for athletes who want to participation in a specific sport. For participation in athletics events, competitions are organised into the following classes labelled in the following manner (IPC, 2011):

- Classes 40-46 include ambulant athletes with different levels of amputations - Athletes in these classes are able to stand when they compete.

Class 42 – 44 the legs are affected.

Class 45 – 46 the arms are affected.

- Classes 55-58 cover wheelchair athletes with different levels of spinal cord injuries and amputations as well as athletes with spinal cord injuries.

  For example, an athlete with a single leg amputation using a wheelchair could compete in the 58 sport class.

When competing specifically in a track event, the athlete's classification starts with the prefix 'T' for track and then 4, which indicates that the athlete is an amputee either standing or 5, using a wheelchair. A final number is assigned to indicate the type of amputation. For example, the participant in this study competes under the classification T43, which means he has a single below knee amputation and runs with a prosthesis). A sprinter in the T44 class would have double below knee amputations and run with prostheses.

Prosthetics for Sprinters with Leg Amputations

The performance of sprinters with amputations has greatly improved over the past 20 years (Nolan, 2008). These improvements coincide with the development of carbon fibre prostheses (Figure 7) used by many sprinters with both transtibial and transfemoral amputations. While there are numerous manufacturers of prosthetics, they all follow similar designs (Nolan, 2008).

There has been research that has concluded that some prosthetic limbs do provide athletes wearing theme with a mechanical advantage over their able-bodied counterparts (Bidlack, 2009; Zettler, 2009; Nolan, 2008). Other researchers have contended that they have found no advantage to wearing these prosthetic limbs when compared with able-bodied sprinters (Burkett, McNameeb & Potthast, 2011; Kram, Grabowski, McGowan, Brown & Herr, 2009). With no overwhelming data definitively stating whether there is an advantage or not, the use of prosthetics will continue to cause debates. The athlete with an amputation who participated in this study wears a specifically designed prosthesis for sprinting.

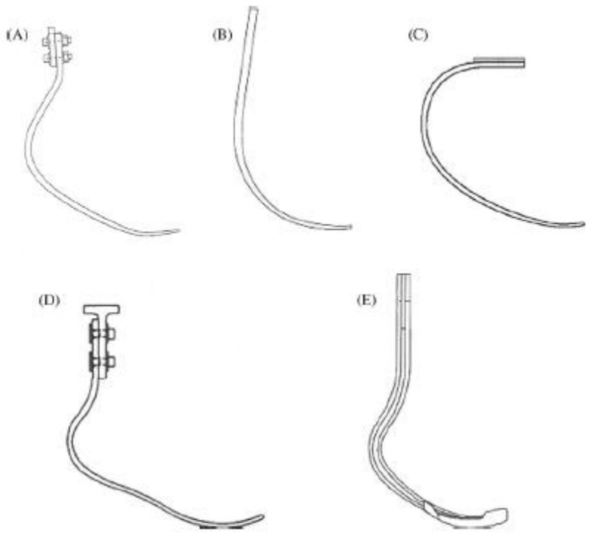


Figure 7. Prosthetic designs used in sprinting. (A) Cheetah (Össur), (B) Flex-sprint (Össur), (C) Flex-run (Össur), (D) Sprinter (Otto Bock), and (E) C-sprint (Otto Bock) (Nolan, 2008)

Single Lower Leg Amputation and Sprinting

Buckley (1999) looked at the sprint kinematics of lower limb amputees and found that the limb, hip and knee kinematics during their sprinting were not comparable to those he found in able-bodied subjects. He reported that the mechanics experienced by amputee sprinters are dependent on the prosthesis worn. In a follow-up study Buckley (2000) found that athletes with single leg amputations had higher hip and knee extension on the side of their amputation (with the sprint prosthetic) when compared to their other leg during the maximal phase of the sprint. This unevenness of gait could create special challenges for establishing and maintaining the rhythmic coordination of running and thus have a limiting impact on running speed.

Athletes with a transfemoral amputation have been shown to have gait patterns that reflect in slower walking, while requiring an increase in energy output (Macfarlane, Nielsen, & Shurr, 1997; Jaegers, Hans Arendzen, & de Jongh, 1995). Athletes with a transtibial amputation display data which is closer in kinetic and kinematic patterns to able body gait (Isakov, Burger, Krajnik, Gregoric, & Marincek, 1996). Asymmetrical gait patterns were evident in the studies of transfemoral amputees (Macfarlane, Nielsen, & Shurr, 1997; Jaegers, Hans

Arendzen & de Jongh, 1995) and less pronounced in transtibial amputees (Buckley, 1999; Isakov *et al*., 1996).

The differences in the mechanics of running between able-bodied athletes and athletes with leg amputations were further supported by a study by Cugini, Bertetti and Bonacini (2006). They concluded that athletes with leg amputations tended to have wider and shorter stride lengths compared to their able-bodied counterparts. They speculated that this difference may be to assist amputee runners in keeping their balance, and they noted that the differences in width and length of stride was related to the length of the runner's the stump. They also found that the rhythmic cadence and sprinting velocity of the amputee runners was lower than their able-bodied counterparts at both the professional and the junior levels. Grabowski, McGowan, Herr, McDermott and Kram (2009) found that sprinters with leg amputations could not generate the same amount as ground force in their prosthetic limb side as on their other side, and that they overcame this imbalance by significantly increasing their stride frequency.

From this information it can be seen that the differences in the sprint kinematics between athletes with lower leg amputations and their able-bodied counterparts are affected by the behaviour of their prosthetic leg. Learning to compensate for disruptions in gait rhythm and in the generation of force must be addressed in their training programmes. A coach would need to keep in mind the body asymmetry of the athlete and find ways to reduce its impact on sprint performance, as well as attend to issues surrounding proper stump care (Howells & McFaul, 2009).

Visual Impairment

Freeman, Munoz, Rubin and West (2007) described a visual impairment as a functional limitation of one or both of the eyes or in the visual system due to a disorder or disease. Visual impairments are usually manifested as reduced visual acuity, contrasts sensitivity, visual field loss, photophobia, diplopia, visual distortion, visual perceptual difficulties, or any combination of the above. These functional limitations can result from congenital, hereditary or acquired.

Classification of Visual Impairment

Vision is normally measured using a Snellen chart. A Snellen chart has letters of different sizes that are read, one eye at a time, from a distance of six meters. The smallest line of letters the individual can read will be expressed as a fraction, *e.g.* 6/18 or 6/24. The upper number refers to the distance the chart is from the individual (6 metres) and the lower number is the distance in metres at which a person with no impairment should be able to read the line of letters (Stevens, 2007; Sacharowitz, 2005).

According to the International Classification of Diseases -10, there are four levels of visual function (WHO, 2012; Abdull, Sivasubramaniam, Murthy, Gilbert, Abubakar, Ezelum &Rabiu, 2009):

1. Normal vision – visual acuity of ≥ 6/12 in the better eye.
2. Moderate visual impairment – visual acuity of< 6/18 to6/60 in the better eye.
3. Severe visual impairment –visual acuity of < 6/60 to 3/60 in the better eye.
4. Blindness –visual acuity of < 3/60 in the better eye.

Three classes of visually impairment have been established for organising sport competitions. These classes are regulated by the International Blind Sports Association (IBSA) and are as follows (IPC, 2011):

1. B1 – An athlete with no light perception at all in either eye or with some light perception but an inability to recognise the shape of a hand at any distance or in any direction.
2. B2 – An athlete who can recognise the shape of a hand and has the ability to perceive clearly up to 2/60. The visual field of the athlete is less than five degrees.
3. B3 – An athlete who can recognise the shape of a hand and has the ability to perceive clearly above 2/60 up to 6/60. The visual field of the athlete varies between 5 degrees and 20 degrees.

For sport competition, athletes with visual impairments are classified into one of the following classes (IPC, 2011):

1. Class 11 for B1 athletes.
2. Class 12 for B2 athletes.
3. Class 13 for B3 athletes.

For track events, the athlete's class starts with the prefix 'T' for track and then '1' which indicates that the athlete is visually impaired. The next number indicates if the athlete is B1, B2 or B3. For example, the participant in this study competed as a T12 athlete.

Visual Impairment and Sprinting

The characteristics of athletes with visual disabilities vary widely, making predictions of athletic performance difficult. If the athlete has been visually impaired since birth, developmental delays may have occurred in their acquisition of both fine and gross motor skills (Freeman *et al*., 2007), which would certainly include running much less sprinting.

The development of motor skills can be measured through the milestones of grasping, sitting independently, crawling, standing and walking. In general, children with visual impairments attain these milestones at later ages than do children with normal vision (Ferrell, 1986). Children with visual impairments tend to miss the sensory cues other children receive from the environment to reach for things or move toward them. Thus, they tend to explore space less, exhibit less overall body movement and learning about their environment. In addition, their movements tend to be less fluid and deviations in posture and gait are more common in children with visual impairments (Hallemans, Ortibus, Meire & Aerts, 2010).

Children with mild and moderate visual impairments can reach the same motor developmental stages as their counterparts with normal vision, although special interventions are recommended (Lee, 2011). A growing body of data on the problems of visual perception in children indicates the value of an individualised case-by-case approach. For example, children with visual impairments may experience subtle kinds of learning difficulties, they may evidence poor eye-hand coordination, low ability to pick out and organize details, weak figure-ground discrimination, and faulty visual target-following (Halliday, 1970). In a study by Kersten (1981) participating in physical activities to music helped alleviate the clumsiness and poor coordination of a group of children with visual impairments.

In terms of visual impairment and running, visually impaired and blind athletes have been shown to expend more energy during a typical locomotor pattern (Buell, 1982). One of the critical challenges found in these athletes relates to their balance control (Portfors-Yeomans & Riach, 2008; Bouchard & Tetreault, 2000). Not only can poor balance lead to poor postural control and a hesitant gait, it also has a negative impact on self-confidence (Bouchard & Tetreault, 2000; Sleeuwenhoek, Boter & Vermeer, 1995). These factors contribute to poor dynamic balance which not only and can lead to increased risk of falls, but also is required for sprinting (Lord & Dayhew, 2001; Rubenstein, Josephson & Robbins, 1994). Research has shown that dynamic balance can significantly improve, thereby improving postural control and gait, reducing the risk of falls and enabling the performance of activities such as running with more success (Jazi, Purrajabi, Movahedi & Jalali, 2012).

Visual cues are used to determine the speed of locomotion, allowing the individual to accurately perceive speed as well as relation to the environment, which is one reason why persons with visual impairments often have shorter stride lengths and more frequent strides than persons without impairments (Shumway-Cook & Woollacott, 2007; Arnhold & McGrain, 1985).

.Cerebral Palsy

Cerebral palsy is an inclusive term which refers to a set of neurological conditions that affect the brain and nervous system and are manifested as a motor impairment. The word palsy means complete or partial muscle paralysis. The more severe forms of cerebral palsy are frequently accompanied by some loss of sensation and uncontrollable body movements or tremors. Cerebral palsy is the most common motor disability of childhood (Berker & Yalçin, 2010; Pakula & Van Naarden Braun, 2009).

Classification of Cerebral Palsy

Cerebral palsy encompasses a spectrum of motor disorders of varying tone, anatomical distribution and severity. Anatomical classification is based on the anatomical region of involvement and severity of the problems (Berker & Yalçin, 2010).The predominant types of motor impairment are categorised as spastic, dyskinetic and ataxic (Berker *et al.*, 2010; Bagnara, Bajraszewski, Carne, Fosang, Kennedy, Ong, Randall, Reddihough & Touzel, 2000).

1. Spastic cerebral palsy

   This is the most common type of cerebral palsy. Approximately 70% to 80% of individuals with cerebral palsy are spastic. Spasticity is defined as an increase in the physiological resistance of muscle to passive motion. It is part of the upper motor neuron syndrome characterized by hyper-reflexia, clonus, extensor plantar responses and primitive reflexes. Spastic cerebral palsy is anatomically sub-divided into three types.

   a. Hemiplegia

      With hemiplegia, one side of the body is involved with the upper extremity generally more affected than the lower. Seizure disorders, visual field deficits and proprioceptive loss are likely. Twenty per cent of individuals with spastic cerebral palsy have hemiplegia.

   b. Diplegia

      With diplegia, the lower extremities are severely involved and the arms are mildly involved. Fifty per cent of individuals with spastic cerebral palsy also have diplegia.

c. Quadriplegia (Total body involvement - tetraplegia)

With quadriplegia, all four limbs and the trunk are involved. When one upper extremity is less involved, the term triplegia is used. Thirty per cent of individuals with spastic cerebral palsy also have quadriplegia.

2. Dyskinetic cerebral palsy

Abnormal movements that occur when the individual initiates movement are termed dyskinesias. Dysarthria, dysphagia, and drooling accompany the movement problem. Mental status is generally normal; however severe dysarthria makes communication difficult and leads the observer to think that the individual has an intellectual impairment. Sensorineural hearing dysfunction also impairs communication. Dyskinetic cerebral palsy accounts for approximately 10% to 15% of all cases of cerebral palsy. Hyperbilirubinemia or severe anoxia causes basal ganglia dysfunction and results in dyskinetic cerebral palsy.

3. Ataxic cerebral palsy

This is the least common type of cerebral palsy. Ataxia is the loss of balance, coordination, and fine motor control. Ataxic children have great difficulty coordinating their movements. Children who can walk have a wide-based gait and a mild intention tremor. Dexterity and fine motor control is poor.

Although these categories are clinically imprecise, they are conceptually useful (Berker & Yalçin, 2010; Bagnara *et al.*, 2000).

In terms of classification for sport competition, it is important to remember that no two people with cerebral palsy are affected in exactly the same way (Sports Coach UK, 2012).The IPC (2011) has established two main groupings in cerebral palsy sport:

1. CP1, CP2, CP3, and CP4 are classes of for athletes with cerebral palsy who use a wheelchair during competition (for swimming, these athletes would use a wheelchair for their other sports).

2. CP5, CP6, CP7, and CP8 are athletes with cerebral palsy who do not use a wheelchair during competition.

Athletes are classified more specifically within one of the main groups, into nine different sport classes based on their functional abilities. A brief description of each of the classes for sport follows (IPC, 2011):

1. CP1 - Athletes with poor functional range of movement and poor functional strength in arms, legs, and trunk. The athletes use electric wheelchairs or assistance for mobility. They are unable to propel a wheelchair. These athletes compete in a wheelchair.

2. CP2 - Athletes with poor functional strength in arms, legs, and trunk. The athletes are able to propel a wheelchair. These athletes compete in wheelchairs.

3. CP3 - The athletes show fair amount of trunk movement when pushing a wheelchair, but forward trunk movement is often limited during forceful pushing. Although showing some trunk movement while throwing, motions are mostly from the arm. These athletes compete in wheelchairs.

4. CP4 -- The athletes show good functional strength with minimal limitations or control problems in arms and trunk. The athletes show poor balance. These athletes compete in wheelchairs.

5. CP5 -- The athletes have normal static balance, but show problems in dynamic balance. A slight shift of centre of gravity may lead to loss of balance. The athletes may need an assistance device for walking, but not necessarily when standing or throwing in athletics field events. The athletes may have sufficient function to run on the track.

6. CP6 -- The athletes do not have the capability to remain still: They show involuntary cyclic movements and usually all four limbs are affected. The athletes are able to walk without any assistance. They usually have more control problems with the arms and they have better leg functions than CP5, especially when running.

7. CP7 -- The athletes have uncontrollable muscular spasms in one half of the body. They have good functional abilities in the dominant side of the body. They walk without assistance but often with a limp due to uncontrollable muscular spasms in the leg. While running, the limp may disappear almost totally. Their dominant side has better development and good follow-through movement in walking and running. Arm and hand control is affected only on the non-dominant side; good functional control is shown on the dominant side.

8. CP8 -- The athletes show a minimum of uncontrollable spasm in one arm, one leg, or one half of the body. To be eligible, these athletes need to have a diagnosis of cerebral palsy or other non-progressive brain damage.

Athletes with cerebral palsy who compete specifically in track events are assigned to a class beginning with “T” for track, and then “3” to indicate cerebral palsy. The final number in their class indicated the level of function. Classes T32 - T34 are for athletes using wheelchairs and T35-T38 for athletes who are ambulant during competition. There were two athletes with cerebral palsy who participated in this study. One is classified as a T37 athlete and the other as a T38 athlete, which means they are both fully ambulatory. The T37 athlete has a lesser functional ability, however, than the T38 athlete.

Cerebral Palsy and Sprinting

Because motor control is the central issue for with persons with cerebral palsy, their running is necessarily affected at some level. Gillette's Children (2009) identified the following problem areas that impact skill performance:

1. Control of muscle movement.
2. Muscle tone (abnormally stiff or loose muscles).
3. Muscle weakness.
4. Reflexes.
5. Balance.

Cerebral palsy causes problems with messages from the brain reaching the muscles. High muscle tone (spasticity or hypertonia) results in muscles that are overly tight or stiff. Low muscle tone (hypotonia) results in abnormally loose muscles and floppy body movements (Gillette's Children, 2009). Some individuals have mixed muscle tone (some parts of their bodies have high tone, and other parts have low tone or tone that fluctuates). Although one type of muscle tone abnormality might be obvious during infancy, other muscle tone problems might appear as a child's nervous system develops (Berker & Yalçin, 2010).

Pope, Sherril, Wilkerson and Pyfer (1993) found that athletes with cerebral palsy exhibited a higher stride frequency and shorter stride length than athletes without cerebral palsy. They attributed this running gait pattern to tightness in the athletes' hip flexors as well as a compensation for possible balance problems. They proposed that coaches of cerebral sprinters should be careful not to have athletes over-stride. They concluded that the best method may be to promote a higher stride frequency to attain higher speeds.

Böhm and Döderlein (2012) completed a similar study on the sprinting gait of athletes with cerebral palsy and found that asymmetry in running gates became more evident as the speed of the athletes increased. This was further supported by the study by Pyanzin, Romanov, Vasilyev and Fletcher (2012) who found that the optimal running patterns of athletes with cerebral palsy were highly individualised and all deviated from the optimal parameters associated with able-bodied sprinters.

One of the most common training methods to improve the coordination of children with cerebral palsy is music and dance (Treating Cerebral Palsy, 2005). It is believed that moving to the beat can help develop a sense of rhythm in their movements. Dance therapy has been proposed to be especially helpful in development of coordination in children with cerebral palsy, because dancing involves different parts of the body and the coordination of moving those parts to the rhythm of the music.

Significant features of cerebral palsy include impaired movement in ambulation and in upper body coordination, as well as problems with balance. Common problems in gait for those with spastic cerebral palsy include short stride length, asymmetrical gait, slowness and unnecessary body movement (Kwak, 2007). Rhythmic auditory stimulation (RAS) training has been found to be effective in improving coordination in rehabilitation settings (Thaut, 2005). In a study by Kwak (2007), there was an overall improvement in general body control and running gait patterns for participants following a six week RAS programme. The participants also showed improvements in their control of critical features of their running, such as cadence, stride length, velocity and body symmetry.

Conclusion

Top level sprinting requires the implementation of precisely timed and well entrained coordinative structures that will produce a successful series of repetitive movements. From a systems perspective, a physical disability can be regarded as an individual constraint that will impact the coordination of coordinative structures that control sprinting. In other words, an impairment will act as an additional rate controller – a controller that is not a factor for an able-bodied sprinter.

- The prosthesis of the amputee athlete can be regarded as a task constraint (equipment) that is part of the system and that must be incorporated into the coordination challenge. A lower limb amputation does not affect the central nervous system, but could impact body schema which in turn could affect movement coordination.

- The lack of detailed visual information available for the athlete with a visual impairment could hinder the capacity to adapt to environmental changes. As a sensory-perceptual impairment, there is central nervous system involvement that could impact movement coordination.

- Cerebral palsy is an impairment of the central nervous system and it does present potentially substantial challenges to the coordination of movement.

Because sprinters with physical disabilities are in the position where some of their systems may have to compensate for other systems in order to coordinate successful movement, it is important for their coaches to approach their performance with an open mind regarding optimal movement kinematics and the implementation of training programmes to optimise how the various systems work together.

Within the context of this study, variability in selected sprint kinematics over the course of a training year will be documented for four Paralympic athletes. This information should help coaches better understand how much variability can be anticipated from top athletes. In terms of training programmes, rhythm has been identified as one of the control parameters that impact on sprint performance, with problems in rhythm associated with tightness and over-striding. The athletes in this study also participated in a rhythm training programme and they shared their perceptions of its potential to improve their sprint performance.

Chapter Three

Methodology

This chapter describes the research design, procedures and methods of analysis used to guide this study.

Design

A mixed methods case study approach was used for this study in which the sprinting performances of four elite Paralympic athletes were measured over time. The advantage of using mixed methods approach is that it supports the incorporation of both quantitative and qualitative data in order to gain a personal impression of the sprint performance of each athlete over a training year. Bartlett (2007) described the approach as supporting semi-quantitative analysis:

> "Sports biomechanists use two main approaches to analysing human movement patterns in sport – qualitative and quantitative analysis. A third approach fits somewhere between the two and is often known as semi-quantitative analysis." (p. 36)

The quantitative method captures large amounts of objective data about each athlete. The qualitative method relies on subjective information that can provide unique insight into each athlete's performance. Coaches need both objective data and subjective information in order to determine how to help athletes' improve their performance. Bartlett (2007) indicated that this approach was suitable for coaches, athletes, physiotherapists and performance analysts' working with athletes as well as movement coordination researchers. Equipment for qualitative analysis that can provide some simple measurements, for example:

- Ranges of motion in joints.
- Durations of sub-phases of the movement, such as the sub-phases in running and stride frequency.
- Distances, such as stride length.
- Joint angles at key times, such as knee angle at take-off.

Procedures

The following procedures guided the data collection and information gathering phases of this study:

Ethics Approval

Recruitment of Volunteers

Test 1

Test 2

Pre-IM™ Test (Test 3)

IM™ Intervention Programme

Post-IM™ Test (Test 4)

Log to Record Subjective Information

Ethics Approval

A formal proposal to conduct this research was submitted to the University Ethics Committee. Because the study involved video recordings of elite athletes, all of whom compete at the international level, special attention was paid to participant confidentiality and security in the storage and subsequent analysis of results. Permission was granted by the committee and the study commenced.

Recruitment of Volunteers

A sample of convenience was used in this study. The investigator approached the sprint coach of one of the Paralympic training squads and requested permission to approach the elite members of the squad and present an overview of this research project. Permission was granted by the coach and a formal presentation was scheduled for a squad meeting.

At the scheduled squad meeting, athletes were given an information letter that described the purpose of the study, any potential risks and benefits associated with participation, and what would be expected of them if they chose to be involved. Once they read the information letter and had the opportunity to ask questions, four elite sprinters expressed their interest in becoming participants.

They all signed the consent form (Appendix A) indicating their willingness to participate in the study. Participants were reminded that they had the freedom to withdraw from testing at any point during the investigation, without any negative consequences. They were then familiarized with the measurement equipment and test protocol during a practical demonstration on the track.

Individual meetings were then held between the investigator and each athlete in order to set up an individualised schedule for the pre-tests, intervention programme and post-test sessions. A copy of these schedules was also given to the coach to facilitate communication and avoid any conflicts with their regular training.

Test Sessions

Four different dates for recording the sprint performances of the volunteers were identified. These dates were distributed throughout the training year, with the final session scheduled at the end of the pre-competition phase of training. The video recordings of all test trials took place on the same outdoor tartan athletics track on a day when there was no other training scheduled and the following procedures were repeated identically during each of the four sessions.

Test Set-up

The following sequence of steps was followed to set-up the test.

1. Clearly mark the starting line, the 10m - 20m - 30m - 40m marks and the finish line at 60m on the tartan track.
2. Set up the video cameras on tripods at the following specified positions and distances for recording of sprint performance. Two Panasonic HDC-HS300 video cameras were positioned on tripods on a line parallel and 10m away from the sprinting lane (Figure 8). Camera One was positioned on the 5m mark to capture the start and initial acceleration phase (from the starting line to the 10m mark). Camera Two was positioned on the 35m mark to capture the maximum acceleration phase (between the 30m to 40m mark).

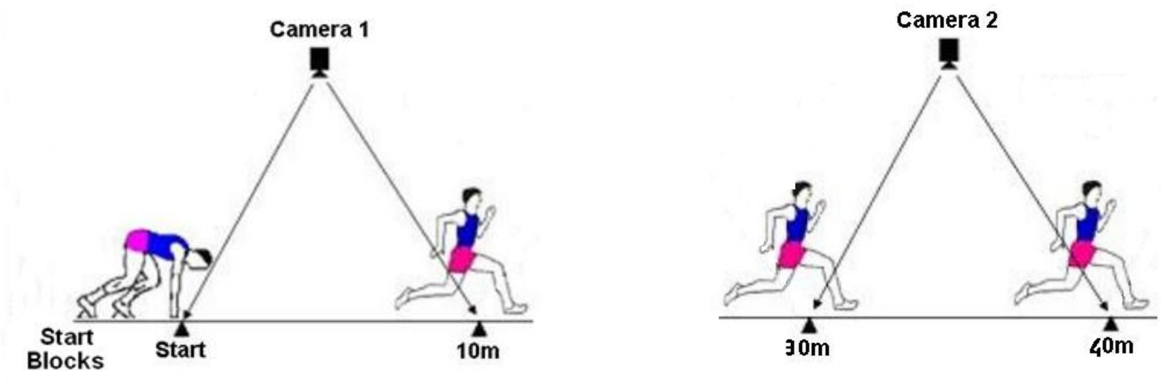


Figure 8. Camera placement for recording the acceleration phase and the maximal speed phase of the sprint

The Test

All participants arrived on time for their individual test sessions. They proceeded to warm-up following their usual pre-race routine. When the athlete indicated readiness, he/she then took the ready position in the starting blocks. The investigator then called out the On your Mark-Set commands, followed by the sharp clap that served as the start signal, which sent the athlete off on a maximal 60m sprint trial. After completion of the trial, the athlete returned to the starting line area. When ready, he/she resumed the ready position in the blocks and the starting process was repeated for a second trial. Environmental conditions for all trials were dry with minimal or no wind. Completion of the warm-up, test trials and warm-down took approximately 50 minutes per athlete.

Recording of the Athletes

The investigator made a digital video recording of each athlete's sprint trial with the support of two other sport scientists from a local sport institute, both of whom had extensive experience in using video cameras to record sprint performance. The following steps were followed in the recording process:

1. When the scheduled athlete finished warming up and indicated readiness, the investigator alerted the two camera operators that the test recording was about to begin.

2. The camera operators started filming when the investigator gave the "Ready" command to the athlete.
3. The filming was continuous until the athlete crossed the finish line at 60m, at which time the "pause" button was pressed.
4. Filming was resumed when the athlete resumed the ready position in the starting blocks and the investigator gave the formal "Ready" command for the second trial.
5. The procedure for filming trial two was identical to trial one.
6. Filming was stopped when an athlete completed the second trial. Each trial was tagged as a separate video clip and stored in a separate file for each athlete on the cameras' hard drives.
7. After this procedure was repeated for each of the four athletes. all apparatus was collected all test-related markings on the track were removed. Cameras and tripods were packed away.

The IM™ Intervention Programme

The IM™ intervention programme consisted of a progression of 12 individual rhythm training sessions in which each athlete attempted to precisely synchronise the performance of a sequence of tasks with different beat patterns presented to them by the Interactive Metronome™ apparatus (Bartscherer & Dole, 2005).

The Interactive Metronome™ is a computer-based, non-invasive training apparatus that requires participants to practice their timing and by challenging them to synchronise the performance of a variety of hand and foot movements with auditory signals created as a beat pattern delivered through a set of headphones (Cosper, Bishop, Lee & Peters, 2009). The IM apparatus includes a laptop computer with Windows XP and IMPro 5.0 software, as well as a hand trigger, a foot trigger and two stereo headphones. The hand and foot triggers are small pressure sensitive pads connected to a cuff strap that is attached around the participant's hand and foot.

The IMPro 5.0 software generates an auditory signal at an adjustable frequency range usually set to 54 beats per second. The participant tries to activate the trigger as the exact time and cadence of the reference beat of the metronome. This action is regarded as a movement task and each task is regarded as a trial. Feedback on timing accuracy is delivered through the headphones by guide sounds each task so that the participant can try to make corrections to reduce timing errors (Bartscherer & Dole, 2005). The software calculates timing error (absolute error in milliseconds) for each trial in the session and at the end of a session, provides a summary report of the following:

1. Total number of trials completed in the session
2. Number of trials considered very early, early, late, and very late
3. Percentage of trials in which the timing error was 15 ms or less
4. The greatest number of trials in a row where timing error was 15 ms or less.

Scott (2009: 51-55) provided the following detailed description of an Interactive Metronome™ training session:

> “The participant stands in a relaxed position facing a control box while wearing a set of headphones through which the metronome beat as well as the feedback (guide sounds) that the computer provides can be heard. For tasks involving the hand, a pressure sensitive glove is worn and for tasks involving the foot, a pressure sensitive foot pad is positioned on the floor. When the participant indicates readiness, the investigator starts the metronome programme and the participant tries to synchronise repetitive hand and foot in time with the beat.
>
> The sensors in the glove and the footpad are attached to a control box which is connected to a computer where the software issues the beat, detects the activation of the sensors, calculates accuracy of the response to the beat, and then records and stores the accuracy of each response on the hard drive.
>
> The guide sound that is delivered after each movement is intended to assist the participant in improving accuracy in timing by indicating whether his/her have responded too early, too late or exactly on the beat. The guide sounds are essential to the training process because they provide auditory

concurrent feedback about the timing accuracy of the movement. An overview of the presentation of guide sounds is presented in Figure 9.There are three guide sounds possible, each of which means something different regarding the accuracy of the participant's timing.

1. If an individual responds to the beat within 15 milliseconds they will hear (in both their ears) a high pitched 'toot' which signals that they are on the beat.
2. The second sound is a rubber 'tang' which is an indication of going just a little bit too slow, or a little bit too fast.
    a. If they hear this sound in their left ear it indicates that they should slow down a little as they are moving too fast and hitting before the beat.
    b. If they hear it in their right ear they should speed up a little as they are moving too slow and are hitting after the beat.
3. The third guide sound is a 'buzz' which is an indication of moving way to fast or way to slow.
    a. If they hear this sound in their left ear it indicates that they should slow down a lot as they are moving way too fast and hitting before the beat.
    b. If they hear it in their right ear they should speed up a lot as they are moving way too slow and are hitting after the beat." (pp 51-55)

	Hit before beat		**Hit on the beat**	***Hit after beat***	
Guide sound	*Sound in left ear*		Sound in both ears	*Sound in right ear*	
Sound	*Buzzer*	*Rubber tang*	Reward sound	*Rubber tang*	*Buzzer*
Meaning to participant	*You are acting very early*	*You are acting early*	You are acting on time	*You are acting late*	*You are acting very Late*

Figure 9. Scott's (2009) summary of the auditory presentation of guide sounds according to accuracy of a participant's movement response

All of the athletes in this study their Interactive Metronome intervention programme twice a week for six consecutive weeks during July and August (Table 2). The individual sessions were delivered in a room at athletics track where privacy was guaranteed. The lighting in the room was consistent and there was minimal ambient noise. No one other than the investigator was present.

At the start of each session, each participant was provided with a brief re-orientation period in which the last activities from the previous session were presented. When the participant indicated readiness, the IM™ was activated to deliver the new sequence of tasks for the training session. The task focus for rhythmic coordination during each session is presented in Table 3.

Observation Log to Record Subjective Information

At the completion of week one, three and the end of the IM™ intervention programme, the investigator asked participants how they found training to obtain an understanding of their subjective feelings on the IM™ system and whether they felt it was of any significance or had an effect on the sprint performance. These questions were open ended style questions designed to grasp a better understanding of the effect of the intervention period.

Table 2

An overview of the intervention period.

Week	**One**		**Two**		**Three**		**Four**		**Five**		**Six**	
Session	1	2	3	4	5	6	7	8	9	10	11	12
Duration (minutes)	90	60	60	60	60	60	60	60	60	60	60	60
Repetitions of Tasks (estimate)	500	300	300	300	300	700	750	600	500	500	300	500

Table 3

The task focus for rhythmic coordination during each intervention session.

Session	Task Focus for Rhythmic Coordination	Tempo
1	Assessment – all possible combinations	54 bpm
2	Assessment – all possible combinations	54 bpm
3	500 repetitions to challenge attention control	54 bpm
4	Hands - Both Hands together, single hand, & alternate hands	54 bpm
		40 bpm
		54 bpm
5	Hands - Both hands together, single hand, & alternate hands	54 bpm
	Feet - Single supported leg heel or toe	54 bpm
	Hands - Both hands together, single hand , alternate hands	54 bpm
6	Hands - Both hands together, single hand, & alternate hands	54 bpm
7	Hands - Both hands together, single hand, & alternate hands	54 bpm
	Feet - Single supported leg heel or toe	54 bpm
	Feet - Single supported leg heel or toe	54 bpm
	Combination hands & feet, cross body (*e.g.* right hand, left heel)	54 bpm
	Feet - Single supported leg heel or toe	54 bpm
8	Hands - Both hands together, single hand, & alternate hands	54 bpm
	Combination hands & feet, cross body (*e.g*. right hand, left heel)	54 bpm
9	Combination hands & feet, cross body (*e.g.* right hand, left heel)	54 bpm
10	500 repetitions to challenge attention control	54 bpm
11	Assessment – all possible combinations	54 bpm
12	Assessment – all possible combinations	54 bpm

For additional detail about the nature of these tasks, see Appendix B.

Analysis of Data

The quantitative data analysis involved the digital video analysis of each athlete's set position, the initial acceleration phase and the maximal running velocity phase of the sprint. The potential of the IM™ training to influence performance was presented as the subjective reports by the athletes themselves.

Analysis of Sprint Performance

The analysis of the sprint performances was comprised of four steps: The selection of the kinematic variables that would be most helpful for coaches, the analysis of the digital video clips of each athlete's performance to generate data in relation to the selected kinematic variables, determination of the reliability of the analysis process and the presentation of the results in descriptive graphs that support a visual identification of variability over the four test periods.

Selection of the Kinematic Variables

The deterministic models for sprinting presented in Chapter Two are commonly used by sprint coaches identify the critical role of stride length and stride frequency in sprint performance. The selection of variables such as these that are observable by coaches with either no technology or low level technology is compatible with the movement observation processes described in the professional teaching/coaching literature (Abendroth-Smith, 1996). Because communication of the results of this research to coaches is a priority of this research, it was decided to select variables of immediate meaning to them.

In addition to the total amount of time taken to complete a sprint, coaches typically use selected kinematic variables to guide their observations of the set position and of sprint performances, either to provide feedback to the athlete or provide focus for training interventions. For analysis of the set position, the following biomechanical variables were recommended by Ping, Robinson and Wing (1986):

1. Forward ankle angle.
2. Back ankle angle.

3. Forward knee angle.
4. Back knee angle.
5. Forward hip angle.
6. Back hip angle.
7. Trunk angle.
8. Angle of the arms.

In relation to the sprinting action, the selected kinematic variables were defined by Hamill and Knutzen (2003) in the following terms:

1. Time, defined as the total period from beginning to completion, expressed for sprinters in 0.00 seconds.
2. Stride length, defined as the distance covered by one stride.
3. Stride frequency, defined as the number of strides per second.
4. Speed, defined as the distance travelled divided by the time it took to travel, expressed for sprinters as meters per second.

Analysis of the Video Clips

The video clips of all of the trials of each athlete were initially stored on the hard drives of the cameras. Following each testing session, the camera used to record the sprint performances of each athlete during the initial acceleration phase (start block to 10m) was connected via a USB cable to a laptop computer. The video clips were then downloaded onto a laptop with another copy made to an external hard drive. Using the Dartfish ProSuite version 4.0.9.0 software, each of the clips from each of the tests was labelled (*e.g.* Participant 1 initial acceleration phase, Test 1, Trial 1). The video clips stored on the laptop were used to complete the analysis. The following is a summary of that process.

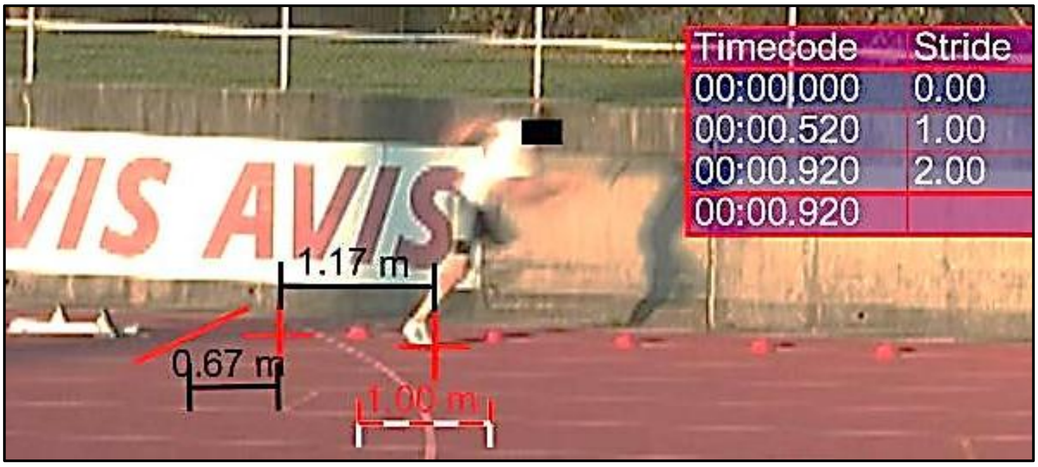
- Separate sessions were scheduled to work with the video clips from each of the test sessions. For example, the process was completed for all of the participants' performances during Test 1 before the process was initiated for Test 2 performances, and so forth.
- Although it is customary in sprint analysis to take the values from the fastest trial (Ping *et al.,* 1986), it was decided to analyse both trials in every test session in order to have enough data to look at trends across the training

year. The coach specifically requested that the test trials be limited to two in order to minimise the impact on her athletes and their training session.

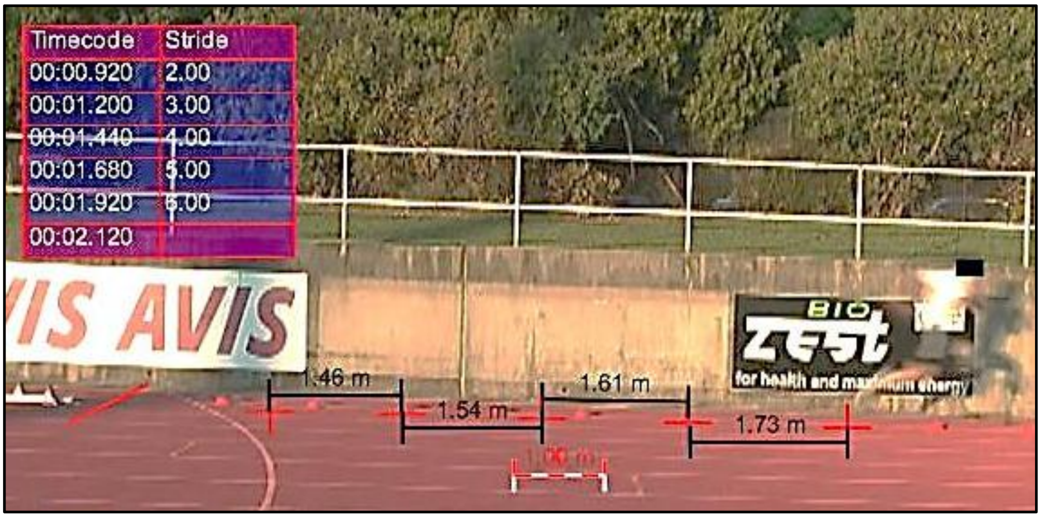
Analysis of the initial acceleration phase included a biomechanical analysis of the set position as well as an analysis of the selected kinematic variables over the first 10m.

1. The video clip was paused when the athlete was in the “Set” position. The DartFish ProSuite software supported the digital tagging of anatomical landmarks and the calculation of the angles of the ankle (forward and rear), knee (forward and rear), hip (nearest to camera) trunk and arm (nearest to carmera) (Photograph 1). The data was manually entered into a Microsoft Excel, 2010 spreadsheet.
2. Analysis of the video clip from the start signal to the 10m mark involved (Photograph 2 and Photograph 3).
    a. Firstly using the measuring tool in the DartFish ProSuite, a one meter reference tool was calculated using the calibration tool in each clip.
    b. The time feature of the software was activated at the moment when the starting signal was given.
    c. Each stride was marked at the point of initial foot contact for each stride. Each stride length was then calculated by the software.
    d. The time feature was de-activated when the sprinter’s foot contacted the track on stride 3.
    e. This data for time and stride length was entered into a Microsoft Excel, 2010 spreadsheet where formulas were applied to calculate stride frequency, speed and acceleration.

Photograph 1. The software supports electronic marking of the key anatomical points and then the calculation of angles at each joint



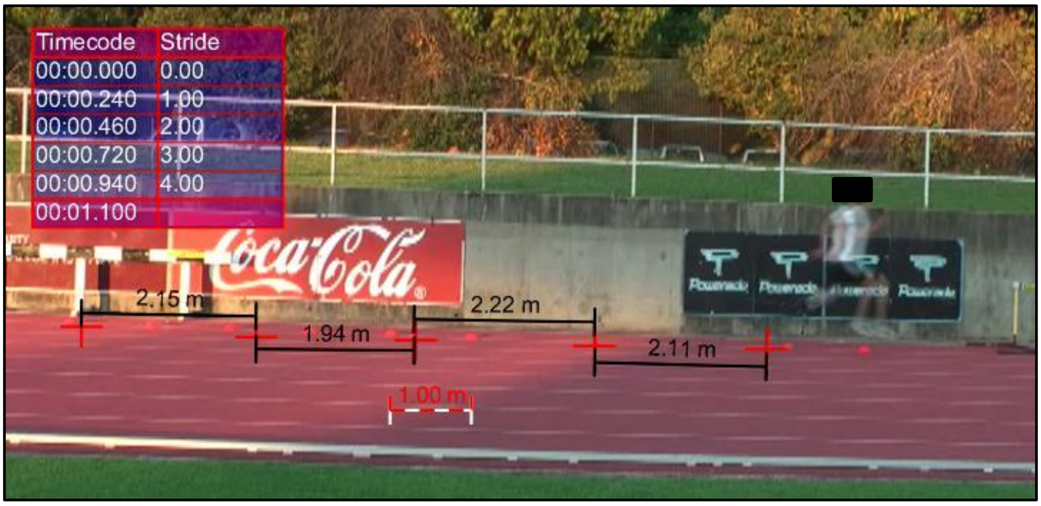
Photograph 2. The software supports electronic marking of the points of ground contact for the first two strides and then calculates both stride length and stride frequency



Photograph 3. The software supports electronic marking of all points of ground contact from the third stride to the 10m mark, and then calculates both stride length and stride frequency

The maximal acceleration phase (from the 30m to the 40m mark) was analysed in a similar way (Photograph 4).

1. The time feature of the software allowed the investigator to mark the time when the 30m mark was reached.
    a. Each stride between 30m and 40m was marked at the point of initial foot contact for each stride. Each stride length was then calculated by the software.
    b. The time feature was de-activated when the sprinter's foot contacted the track on the last stride within phase.
    c. This data for 30m - 40m time and stride length was entered into a Microsoft Excel, 2010 spreadsheet where formulas were applied to calculate stride frequency, speed and acceleration.



Photograph 4. The software supports electronic marking of all points of ground contact from the third stride to the 10m mark, and then calculates both stride length and stride frequency

Reliability of the Video Analysis Process

Reliability is concerned with the accuracy of the assessment process in terms of its consistency or repeatability (Thomas & Nelson, 2001). If an assessment process cannot yield the same results upon successive trials then the instrument is not reliable. For this study, reliability was defined as the consistency with which the investigator digitised and produced the data in relation to the selected kinematic variables of the performances of each of the athletes. It was established by determining the repeatability of the analysis through the re-analysis of the recordings three months after the original analysis.

Two sessions were scheduled for the re-analysis of video clips. During the first session, clips of the fastest trials were selected at random for re-analysis from the baseline test periods (Pre-Test 1 and Pre-Test 2). During the second session, clips of the fastest trials were selected at random from Pre-Test 3 and from the Post-Test). The identical process described above for the original analysis was followed during these two sessions. After completing the re-analysis of each the selected trials, a comparison was made between the initial analysis and the re-analysis. The standard for an acceptable agreement rate was set at 90% (Thomas & Nelson, 2001). A summary of the results of these comparisons is presented in Table 4.

Table 4

Percentage of agreement between initial analysis and re-analysis of all variables.

Kinematic Variable Measured	**Agreement rate with 1st Analysis**
1st Stride	96.4%
2nd Stride	95.6%
Average stride length (3rd stride to 10m)	95.8%
Time at 5m	94.9%
Time at 10m	93.1%
Speed at 5m	92.4%
Speed at 10m	91.1%
Acceleration at 10m	90.7%
Average stride length (30-40m)	96.7%
Time (30-40m)	97.2%
Average speed (30-40m)	95.1%
Acceleration (30-40m)	92.3%
Total Agreement Rate	**94.4%**

Description of Variability

Variability refers to the extent to which data points differ from each other (Ott & Longnecker, 2010). In biomechanical terms, this means how the angles created by the body in the set position differ from each other during each of the four tests, and how the kinematic variables of stride length, stride frequency, time and speed differ from trial to trial and test session to test session, for each of the Paralympic athletes. For the set position, a calculation of Mean, SD and Variance were made for each of the biomechanical variables. For the initial acceleration phase and the maximal running velocity phase, Mean, SD and Variance were calculated for stride length, stride frequency, time, speed and acceleration. The kinematics of each athlete's performance for each of their trials was also presented in the form of a graph to allow a visual examination of where and how much variability occurred in each of these variables during the training year.

Report of Subjective Perceptions about IM™ Training

The subjective information gathered from each of the athletes and recorded in the investigator's log were presented in narrative form in Chapter Four and used to support the discussion of the results in Chapter Five of this study.

Conclusion

The purpose of this study was to gain insight into the sprinting of elite athletes with disabilities in order to expand coaches' knowledge of the variability that can be expected in the biomechanics of their start and their sprint kinematics. This study also was concerned with the athletes' perceptions about the potential of participation in an Interactive Metronome™ Training Programme on their sprinting performance.

Four Paralympic sprinters from three different disability groups volunteered to participate in this study. Each athlete's sprint performance was video recorded during four separate test sessions distributed over their training year. Their set position and two separate phases of their sprint were digitally analysed. The intervention programme was implemented between Test Session 3 and Test Session 4. A log of their perceptions about their experiences was recorded.

Seven biomechanical features of the set position and the kinematic variables of stride length, stride frequency, time and speed were identified as critical indicators of sprinting performance. The results for each athlete are presented in the following chapter.

Chapter Four

Results

The following sections present the results for each of the following four Paralympic athletes.

1. A single below knee amputation (Class T43 - Male)
2. Visual impairment (Class T13 - Female).
3. Cerebral palsy (Class T37 – Male)
4. Cerebral palsy (Class T38 – Male)

Each section begins with a brief description of each athlete, followed by the presentation of descriptive data gather during four test session distributed over the training year (Pre-Test 1, 2 and 3, and the Post-IM intervention Test 4). The sections are organized to answer the two research questions (with sub-questions) that guided this study.

1. What variability can be observed in the sprinting kinematics of Paralympic sprinters?

   a) What variability can be observed in the biomechanical features of the set position of the sprint start of a Paralympic athlete over the course of a training year?

   b) What variability can be observed in stride length and stride frequency during the initial acceleration phase over the course of a training year?

   c) What variability can be observed in stride length and stride frequency during the maximal running velocity phase over the course of a training year?

2. Does a rhythm training programme have the potential to influence the sprinting performance of a Paralympic athlete?

   a) During the initial acceleration phase.

   b) During the maximal running velocity phase.

Case Study One

Participant One was born in South Africa in 1985. He was a promising sportsman as a youth when at the age of 18, his right leg was amputated after an accident. He reported that with this accident he lost all interest in sporting endeavours. However, several years later during his tertiary studies, he was convinced by family and friends to return to sport and to try running. He started to train and found his focus in sprinting. He progressively increased the time and effort he put into training and decided he wanted to compete at the elite level in Paralympic sport in the 100m and 200m. As a single below knee amputee, he was classified in the T44 class. In 2012 his personal best times were 11.08s in the 100m and 22.49s in the 200m.

Variability of the Sprinting Kinematics of Participant One

Data were collected during four testing sessions distributed throughout the training year. The data are presented to answer the three sub-questions related to variability in his sprinting kinematics.

Variability in the Set Position

The results of the biomechanical analysis of the set position for each of the four test sessions are presented in Table 5. Variability is reported for each of the six biomechanical features of the set position for Participant One during each of the four test periods. There is no data for his rear ankle because his rear leg is the leg with the prosthesis (he has no rear ankle).

The angles he created for his rear knee (191.9) and front hip (222.3) demonstrated the largest variability over the course of the training year. This could indicate that this athlete’s coach had adjusted his sprint start slightly, adjusting his weight distribution either forward or backward, which could have an advantageous effect on his start performance if the optimal position could be found. With this having a prosthetic leg this weight distribution is important as it would facilitate an more optimal stride length and compression of the prosthesis. Unfortunately, this is an athlete specific action, depending on numerous personal attributes and requires much trial and error to find the optimal for the athlete.

Table 5

Results of the biomechanical features during the four tests for Participant One.

	Pre-Test 1		**Pre-Test 2**		**Pre-IM Test 3**		**Post-IM Test 4**		**Mean** ± SD	**V**
	1st Trial	**2nd Trial**	**1st Trial**	**2nd Trial**	**1st Trial**	**2nd Trial**	**1st Trial**	**2nd Trial**		
Front Ankle	118.9	115.4	109.4	110.3	107.9	103.3	113.8	115.0	111.8 ± 4.9	24.7
Back Ankle										
Front Knee	107.5	115.8	108.2	93.4	107.0	102.0	91.3	103.8	103.6 ± 8.1	64.9
Rear Knee	120.8	132.9	118.4	100.2	92.7	101.7	98.3	115.5	110.1 ± 13.9	191.9
Front Hip	65.7	72.3	63.1	51.2	41.7	34.4	49.7	31.6	51.2 ± 14.9	222.3
Trunk	31.7	26.5	31.9	34.6	18.2	31.4	32.2	44.3	31.4 ± 7.3	53.7
Arms	113.8	108.7	115.2	108.4	107.5	122.7	107.1	113.3	112.1 ± 5.3	28.2

Variability during the Initial Acceleration Phase (0-10m)

The following figures (Figures 10 – 15) report the results of the analysis of the key performance indicators during the initial acceleration phase of the sprint for Participant One over the four testing sessions. A complete table presenting the data collected on the kinematics of this initial acceleration phase is presented in Appendix C.

The relationship between the first two strides out of the blocks and their effect on time is shown in Figure 10. It is noticeable that the first stride maintains a stable length throughout the eight trials. However, the second stride is more variable and may be the key to having an impact on the time for this phase of the sprint.

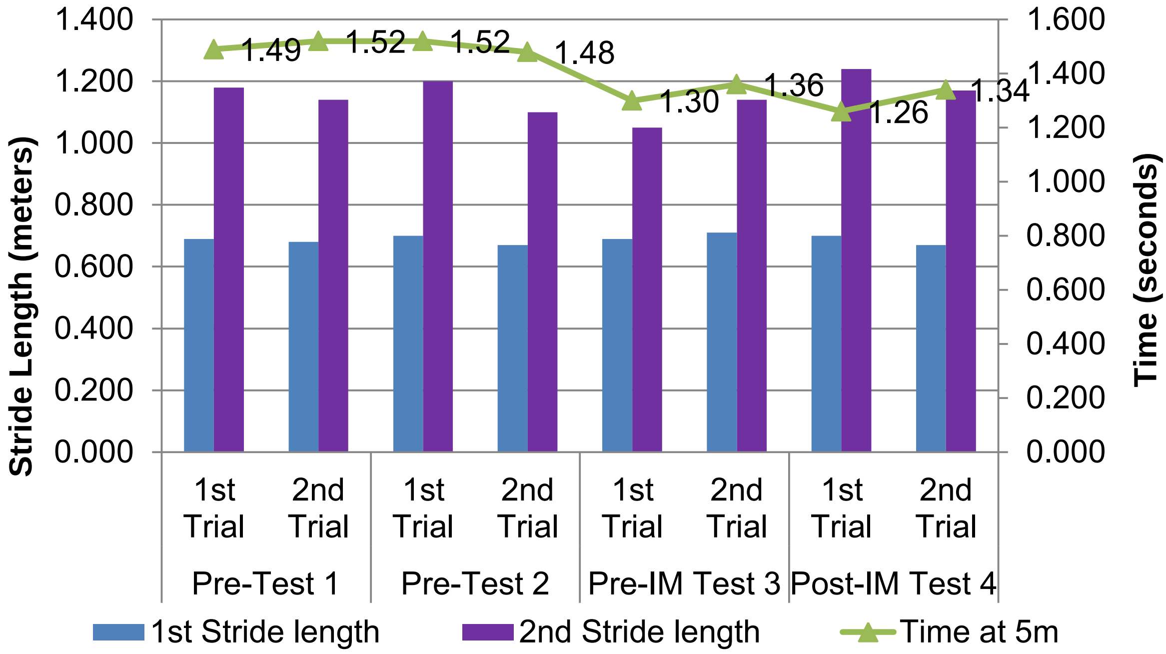


Figure 10. First two stride lengths and time taken during the initial acceleration phase for Participant One

The critical role of stride length for this athlete is again evident when the kinematics for the third stride through the 10m mark are analysed. In In Figure 11, it can be seen that the average stride length for this athlete varied between 1.42m and 1.584m. Each time the stride length dropped, the time increases and vice versa. This pattern is mirrored when stride length is analysed in relation to speed (Figure 12). These two figures illustrate how important it is for this participant to find an optimal stride length that will produce fast times over the first 10m of the sprint.

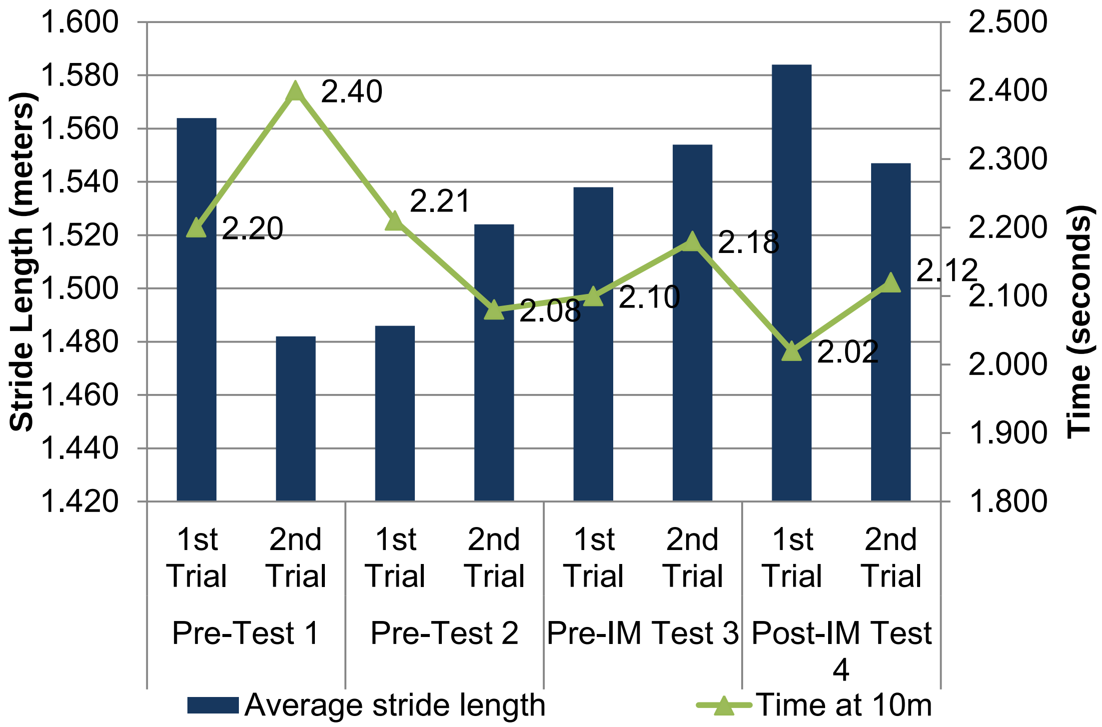


Figure 11. Average stride length (3rd stride to 10m) and time taken during the initial acceleration phase for Participant One

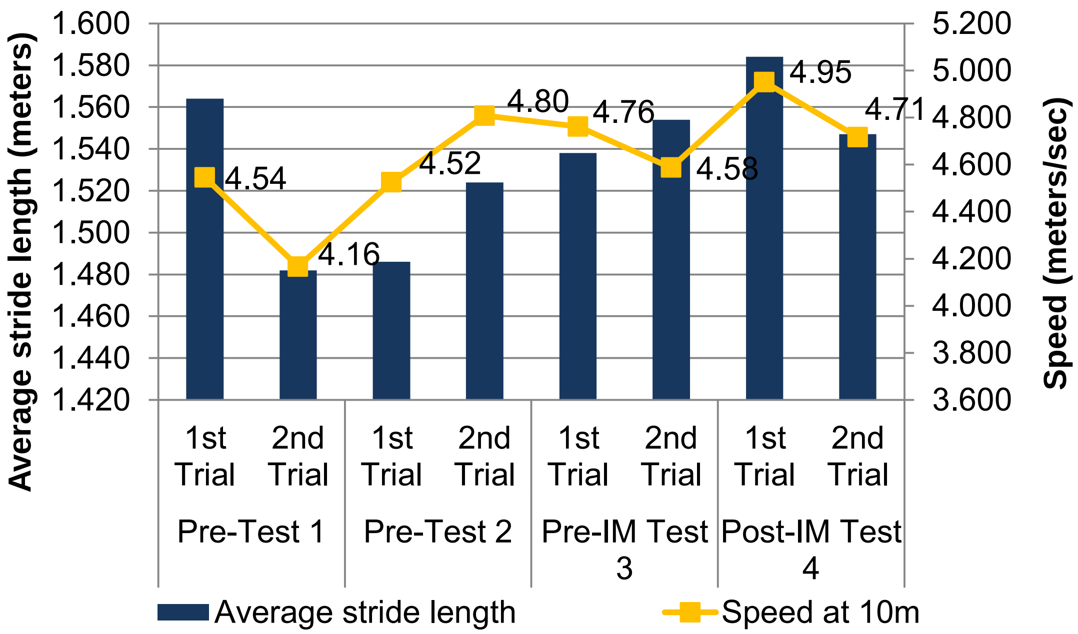


Figure 12. Average stride length (3rd stride to 10m) and speed during the initial acceleration phase for Participant One

In *Figures 13* and 14, variability in stride frequency is shown in relation to speed for this athlete. There does not appear to be a clear link between the stride frequency and either time or speed from the third stride to 10m. Stride frequency varies only between 2.94 and 2.80 strides per second.

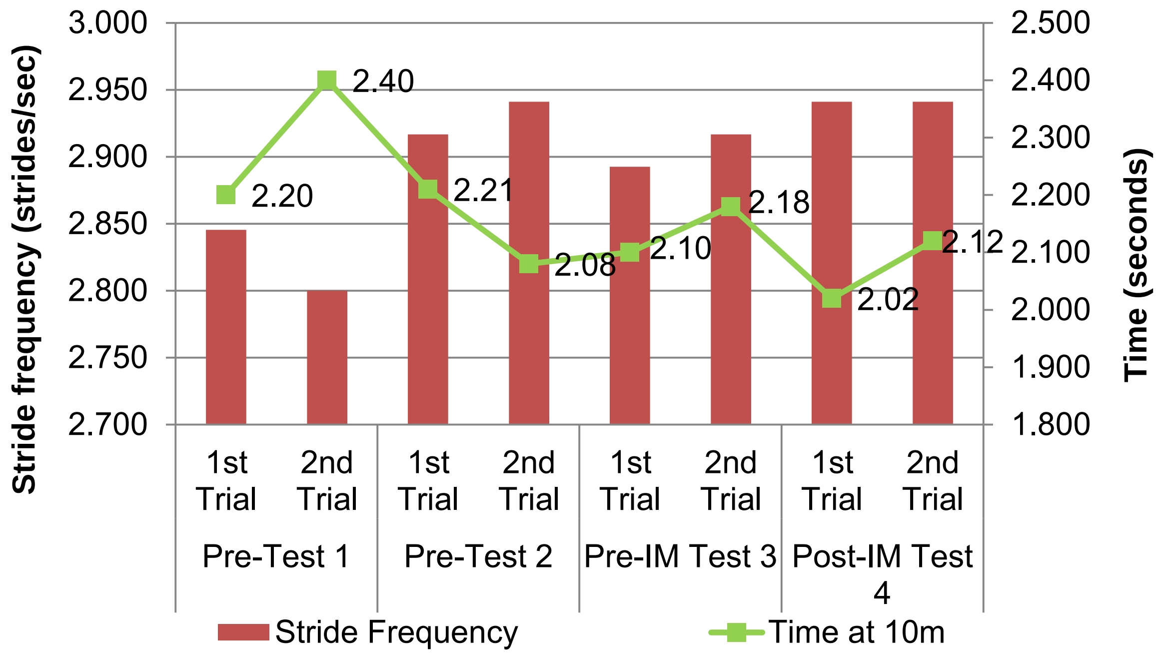


Figure 13. Stride frequency and time taken during the initial acceleration phase for Participant One

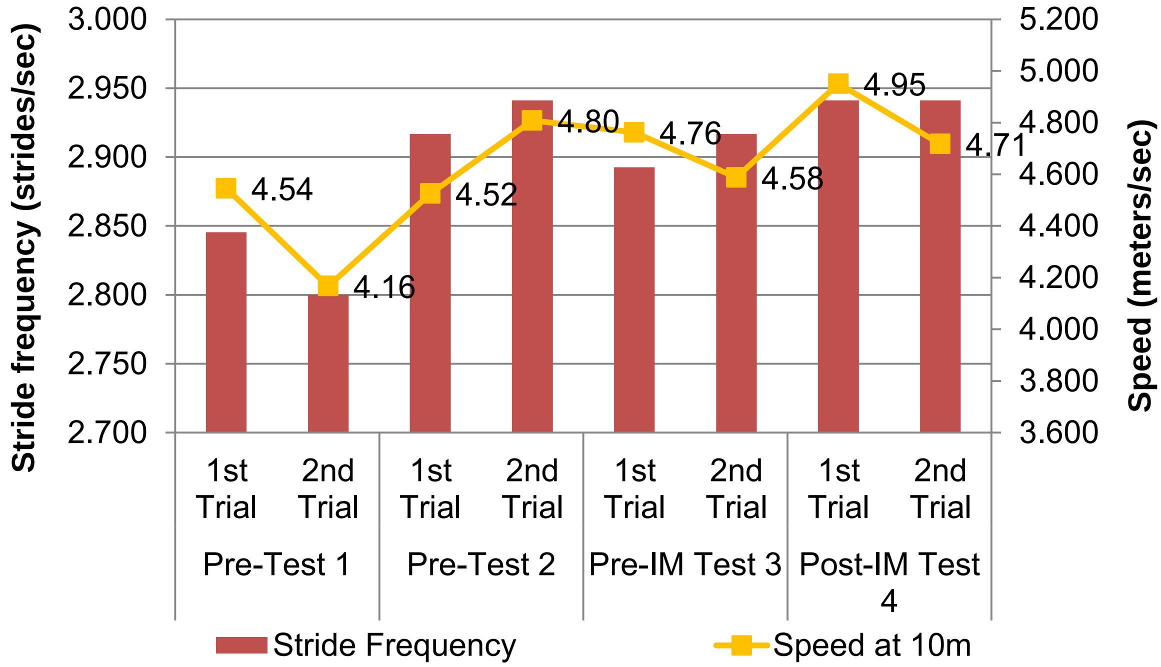


Figure 14. Stride frequency and speed during the initial acceleration phase for Participant One

The correlation between stride length and stride frequency during the initial acceleration phase is presented in Figure 15. Although the correlation calculation over all four test sessions is not strong (r = 0.40), it can be noted that stride length became shorter as stride length became longer on five out of the eight trials. For both of the trials on Test 1 (the beginning of the training year, circled in red), a lower stride frequency can be noticed and the variability can be attributed to stride length. For the remaining tests, Test 2 (circled green) and Test 3 (circled yellow), a higher stride frequency is seen with a slightly longer stride length on the second trial. On Test 4 (the culmination of the training year) the highest rates of stride frequency and average stride length were achieved and the fastest times were recorded. This shows the importance of finding the optimal combination of stride frequency with stride length during the initial acceleration phase of the sprint.

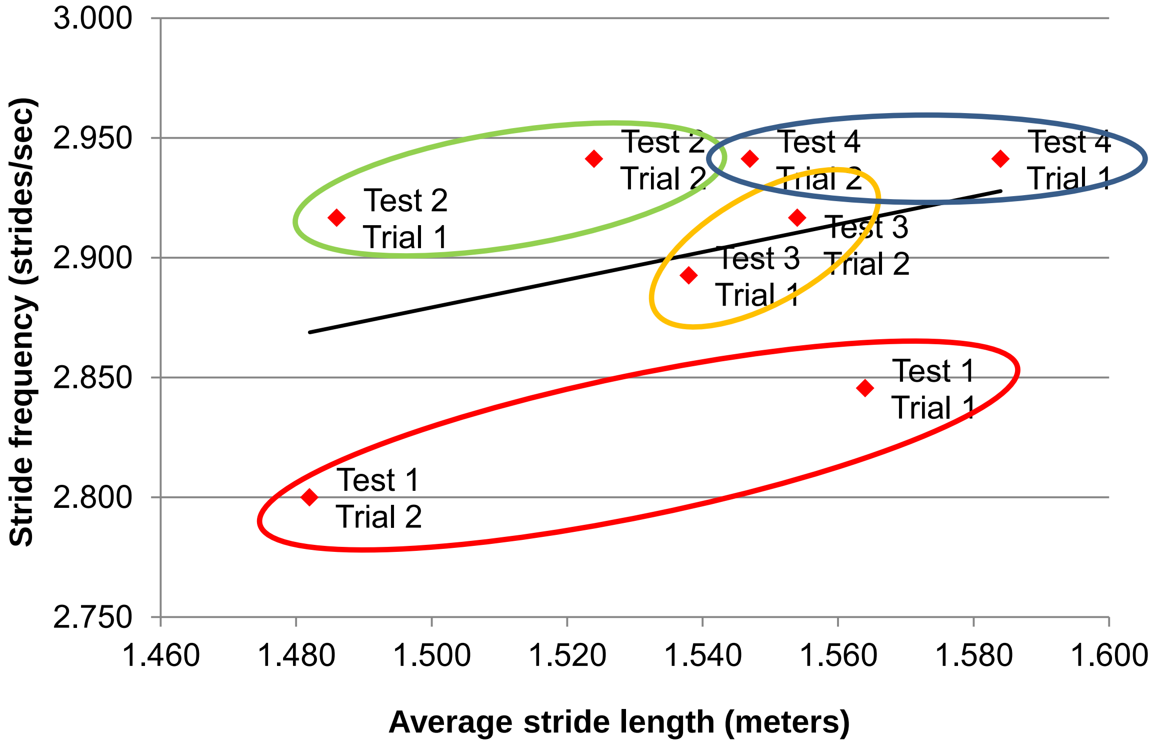


Figure 15. Correlation between stride frequency and stride length during the initial acceleration phase for Participant One

Variability during the Maximal Running Velocity Phase (30m-40m)

The following figures (Figures 16 – 20) report the results of the analysis of the key performance indicators during the maximal running velocity phase of the sprint for Participant One over the four testing sessions. A complete table presenting the data collected on the kinematics of this phase is presented in Appendix C.

Stride length from the 30m to the 40m mark increased progressively over the training year (Figure 16). However, the athlete's time over these 10m became progressively slower over the first three test sessions (from 1.05s on Test 1 Trial1 to 1.20s on Test 3 Trial 1). The improvement in time between Test 3 Trial 2 to Test 4 Trial 2 (1.20s to 1.04s) may be more related to stride frequency. Figure 17 documents the same pattern for changes in speed, with the increase from 8.33 m/sec to 9.61 m/s achieved respectively during Trial 3 and Trial 4. There was a slight increase in stride length between these two trials, but apparently increases in stride length did not produce faster time or speed on the first three trials.

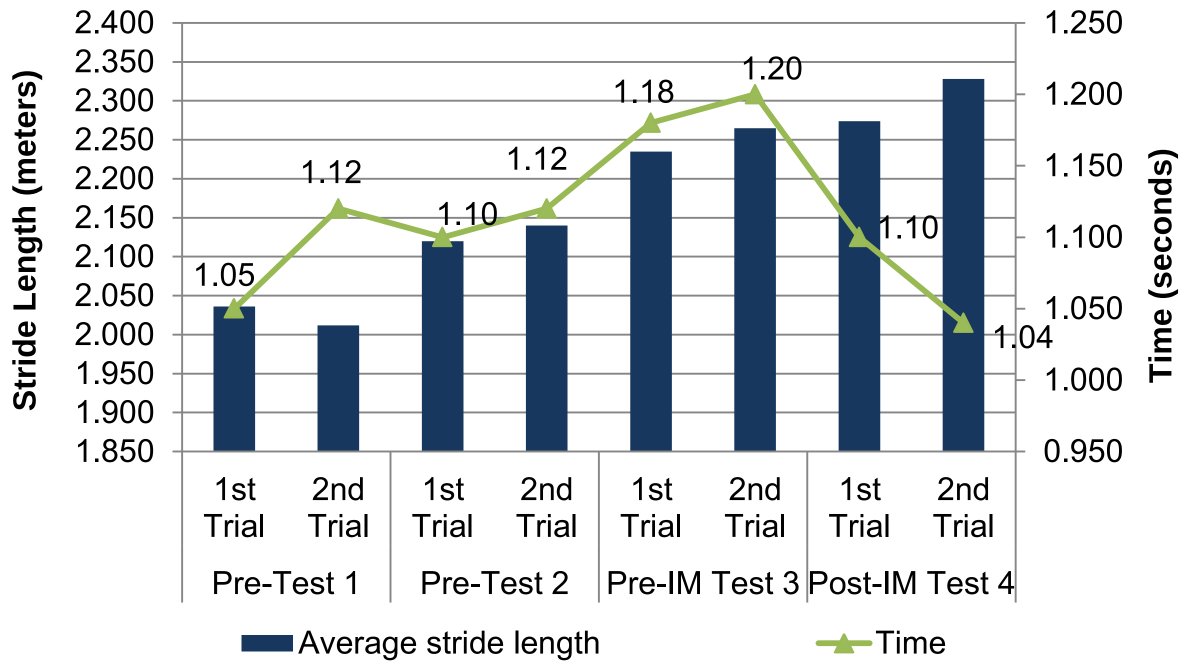


Figure 16. Average stride length and time taken during the maximal running velocity phase for Participant One

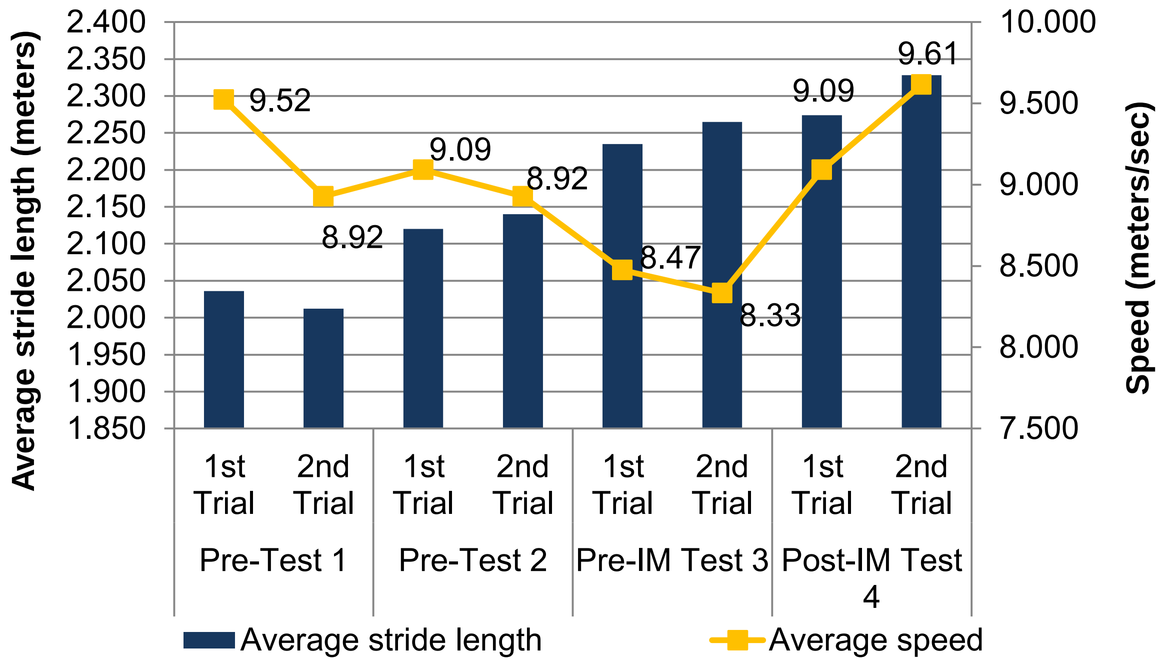


Figure 17. Average stride length and the speed during the maximal running velocity phase for Participant One

When stride frequency from the 30m to the 40m mark is compared to time (Figure 18) and to speed (Figure 19), this athlete only fluctuated between 3.70 to 4.03 strides/sec (a difference of only 0.33 stride/sec) over the course of the training year. Time and speed did not appear to improve in relation to the stride frequency. For example, the slowest trial (1.20s) and the fastest trial (1.04s) had identical stride frequencies (4.03 strides/sec).

It can be observed that stride frequency is always shorter on the first trial than on the second trial during every test session. This could be an artifact of the two-trial testing session. Although the athletes were asked to sprint as fast as possible on each trial, it is possible that this athlete used the first trial to get himself prepared for an all-out effort on the second trial, and subconsciously lowered his stride frequency on each of the first trials.

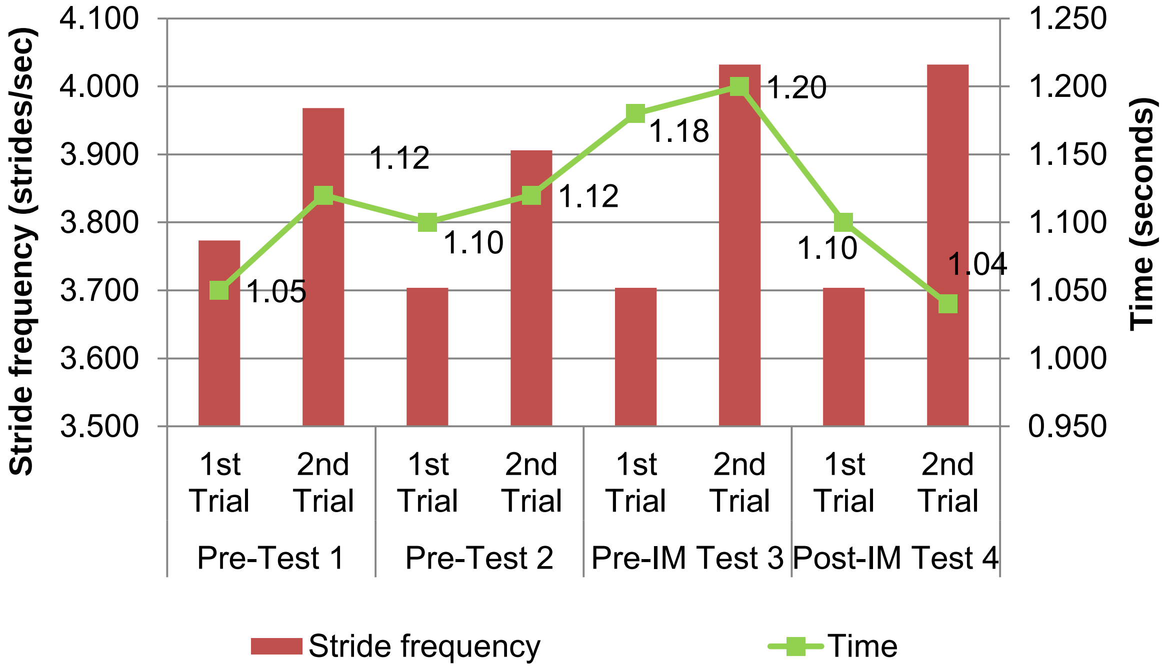


Figure 18. Stride frequency and the time taken during the maximal running phase for Participant One

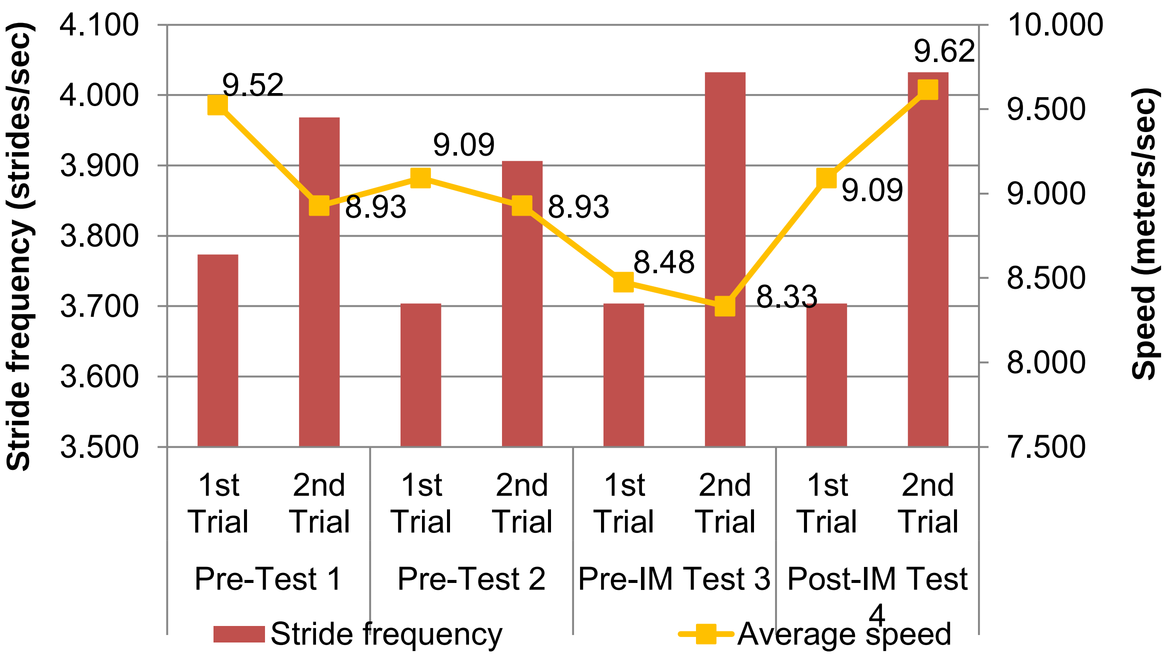


Figure 19. Stride frequency and the speed during the maximal running phase for Participant One

The correlation between stride frequency and stride length during the maximal running velocity phase was plotted (Figure 20) and found to have a very weak correlation (r = 0.15). The following can be noted:

- Although stride frequency was lower on the first trial of every test (circled in red), stride frequency was increased on each of the second trials (circled in blue).
- The difference among the four testing sessions is evident (circled in blue). Stride length progressively increased throughout the training year (2.01m to 2.38m) and appears to be the key performance indicator for this athlete's speed. The progressive increase in stride frequency (from 3.97strides/sec to 4.03 strides/sec) is small but does support the importance of establishing an optimal relationship between stride frequency and length.

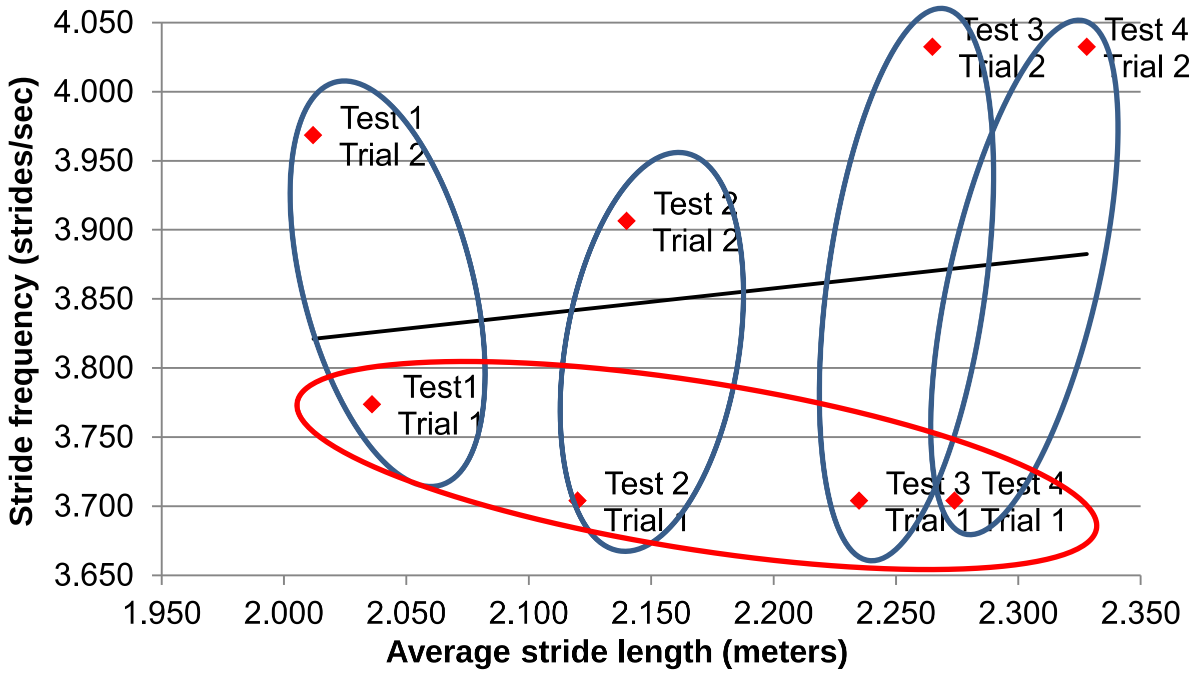


Figure 20. Correlation between stride frequency and average stride length during the maximal speed phase for Participant One

Summary of the Variability Observed in the Sprinting Kinematics of Participant One

Summary: Variability in the Set Position

The angles he created for his rear knee and front hip demonstrated the largest variability over the course of the training year. Being a single leg amputee, the first few strides out of the blocks often determine the end result of the race, as if the athlete can find the optimal biomechanical position for him, then he would be able to leave the blocks and achieve an optimal stride length and compression in his prosthesis which would then lead to further optimal stride lengths. This optimal position for him is a very personal attribute and can change in different environmental conditions and depending on his personal attributes at the time of the sprint.

Summary: Variability during the Initial Acceleration Phase (0-10m)

This athlete's first stride from the blocks is with his able leg and the second stride is with his prosthetic leg. The key to a fast time for coming out of the blocks appears to be related to increasing the length of his second stride with the prosthetic leg while his first stride remains fairly consistent. Coming out of the blocks comfortably with step 1 and step 2 is critical to achieving a faster time speed at 10m.

This athlete's average stride length for this athlete varies between 1.48m and 1.58m (a difference of 0.10m). The time for this athlete varies between 2.4s and 2.02s (variation of 0.38s). There does appear to be a trend that with a longer average stride length, a faster time and speed from the 3rd stride to the 10m mark is achieved. This athlete's stride frequency only varies between 2.94 to 2.80 strides/sec (a difference of 0.14 stride/sec). No trend is noticeable linking higher stride frequency directly to a decrease in time and speed at 10m. However, when stride frequency dropped to its lowest point, the slowest time was recorded, suggesting that there may be a threshold for stride frequency below which time and speed will be impacted negatively.

The correlation between stride frequency and stride length is not strong (r = 0.40). This supports the observation that average stride length is more critical than stride frequency to achieving fast time and speed in the initial 10m. However, stride frequency still must receive attention because it is a critical component of sprinting.

Summary: Variability during the Maximal Running Velocity Phase (30m-40m)

Stride frequency showed minimal variation over the four testing sessions, leading to the observation that stride length was the key performance indicator that increased progressively. Somewhat surprisingly, the 30m to 40m times got progressively slower over the first three test sessions and then improved sharply on Test 4. It must be noted that the fours test sessions were distributed over the training year and that Test session 4 corresponded to the peak period for the athlete's competition. With this in mind, one would expect the fastest time would be achieved on Test 4 as a function of the periodised training year plan followed by athlete with his coach.

Variability in stride length was more evident. The lack of a strong correlation between stride length and stride frequency over the four test sessions which could suggest a very inconsistent sprinting gait (r = 0.15). However, it could be that the athlete and coach were manipulating stride length throughout the year while playing with stride frequency slightly. The goal – an optimal relationship between stride frequency and stride length – would be targeted for the end of the season when the major championship occurred.

The Potential of Interactive Metronome Training™ to Influence the Sprinting Performance of Participant One

Participant One was actively involved in the Interactive Metronome Training™ programme during the period between Test Session 3 (Pre-IM training) and Test Session 4 (Post-IM training). A comparison between his pre-test and post-test scored on IM precision timing is presented in Figure 21. It can be seen that there was an improvement in the millisecond accuracy following the intervention period on tasks for the hands only, feet only, left side of body, right side of body and bilateral. Table 8 presents the total summary for all task repetitions (3819) in the programme, and indicates that Participant One achieved a

36.6% improvement in the precise timing of his movements after completing the intervention programme.

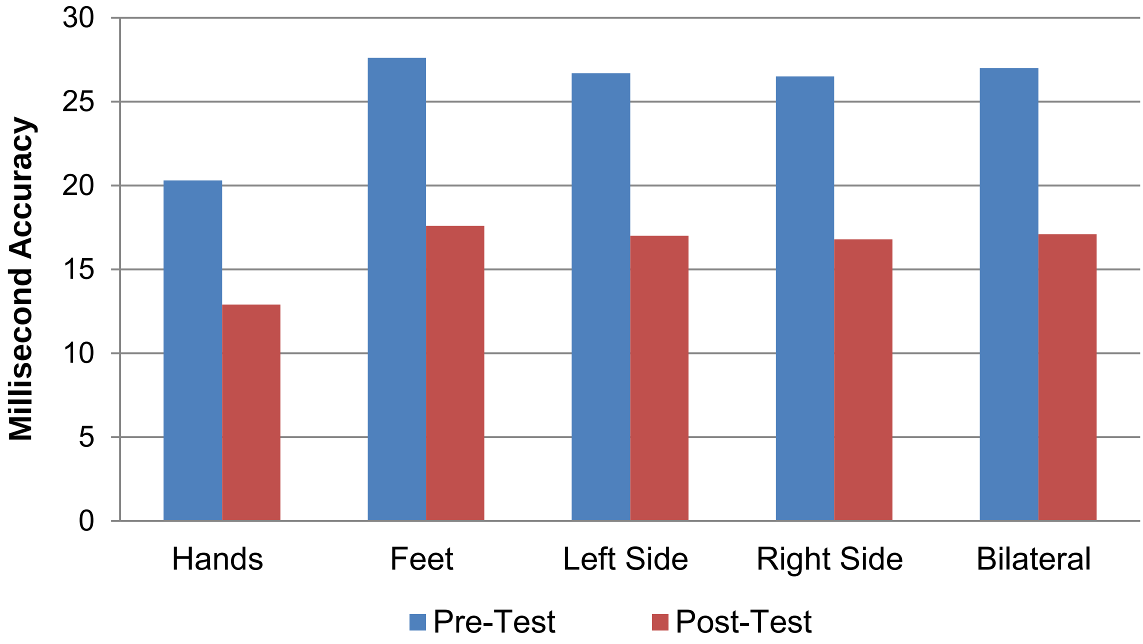


Figure 21. Millisecond accuracy improvements from the pre-test evaluation to the post-test evaluation in the IM training

Table 6

Pre- and post-test adjustment values and improvement following IM™ training for Participant One.

Total Repetitions	Pre-Test Adjusted Value	Post-Test Adjusted Value	Pre- to Post-Test Improvement
3810	37.70	23.90	36.6%

Any signs of possible influence of IM™ training on the sprinting performance of Participant One would have to be found in the differences in the sprint kinematics reported for Pre-IM Test 3 and Post-IM Test 4. The presentation of this data in the following figures is limited to the performance indicators of time, stride length and stride frequency in order to make this comparison clear.

The Potential Influence of IM™ training on the Sprinting Kinematics of Participant One during the Initial Acceleration Phase (0-10m)

The following trends can be noted after the IM training for three of the key performance indicators during the initial acceleration phase:

- Time decreased slightly - the participant ran faster (Figure 22).
- Stride length increased slightly (Figure 23).
- Stride frequency increased slightly then stabilised (Figure 24).

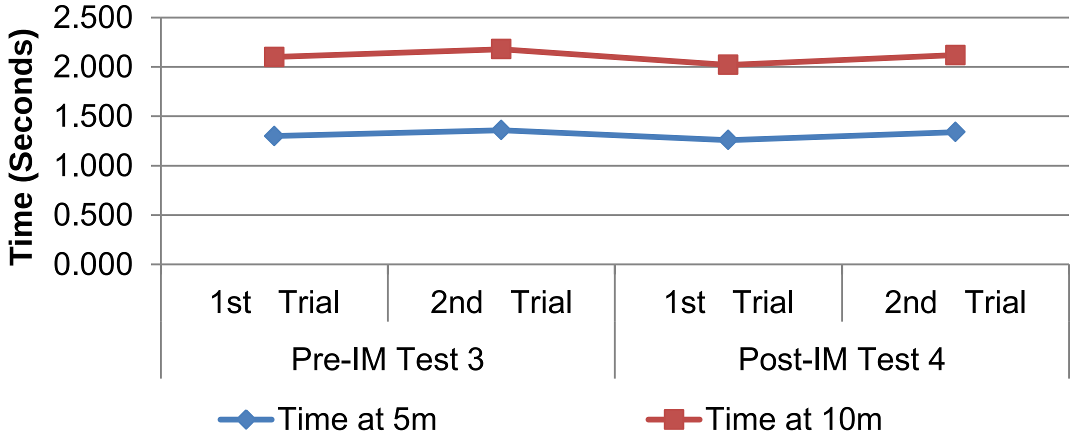


Figure 22. Time at 5m and 10m during the initial acceleration phase for Participant One from pre- to post- IM™ training

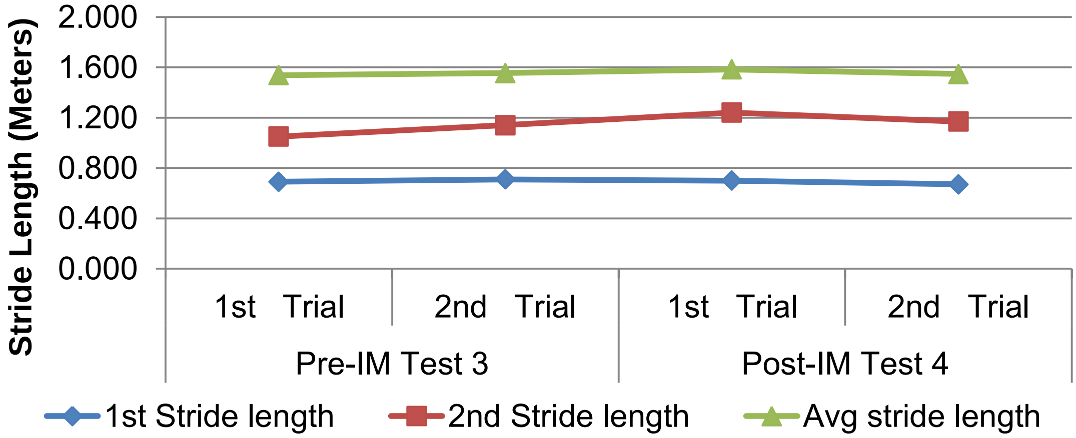


Figure 23. Stride length during the initial acceleration phase for Participant One from pre- and post-IM™ training

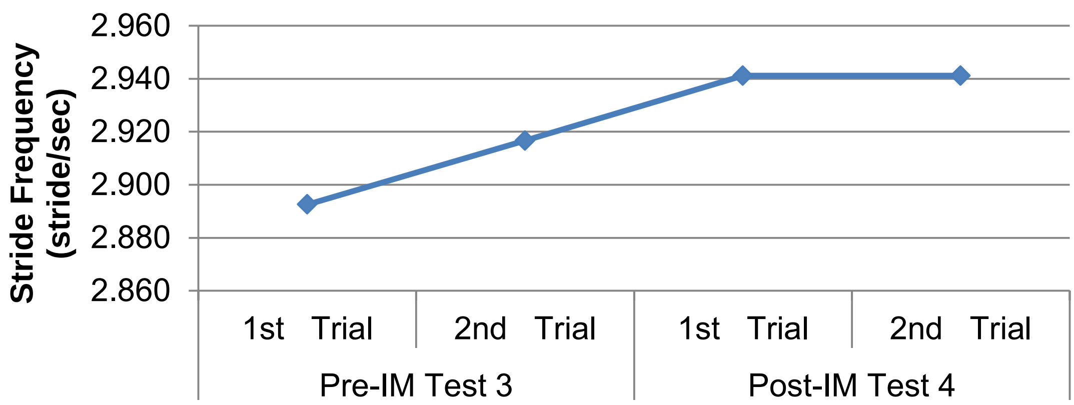


Figure 24. Stride frequency during the initial acceleration phase for Participant One from pre- to post-IM™ training

If IM™ training had any influence on the initial acceleration phase, it would be on increasing stride frequency, which would have a positive impact on time.

The Potential Influence of IM™ Training on the Sprinting Kinematics of Participant One during the Maximal Speed Phase (30m-40m)

The following trends can be noted after the IM training for three of the key performance indicators during the maximal running velocity phase:

- Time decreased - the participant ran faster (Figure 25).
- Stride length increased slightly (Figure 26).
- Stride frequency was inconsistent among the 4 trials, but identical when the trials between the two sessions are paired (Figure 27).

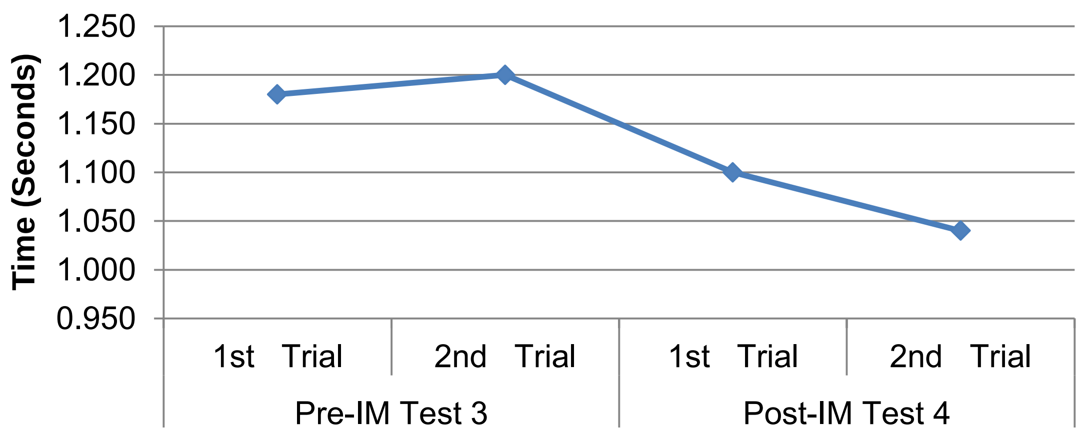


Figure 25. Time during the maximal speed phase for Participant One from pre- to post-IM™ training

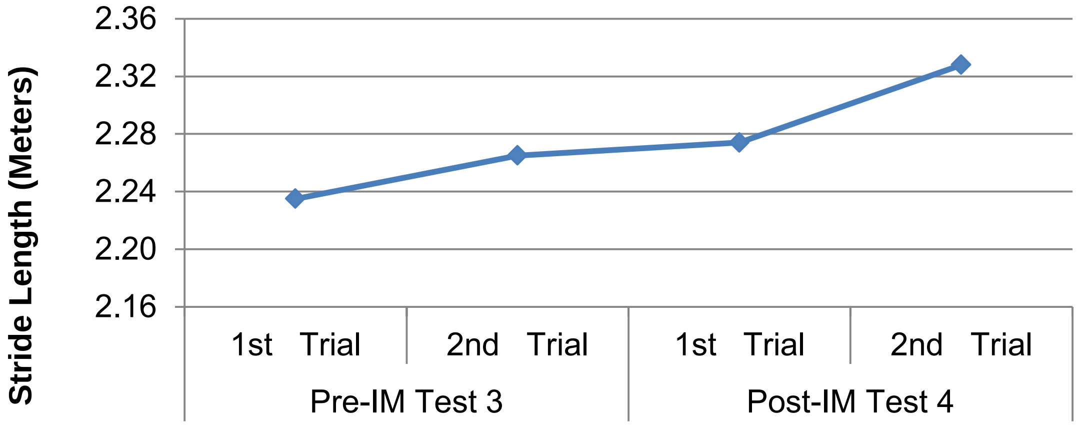


Figure 26. Stride length during the maximal speed phase for Participant One from pre- to post-IM™ training

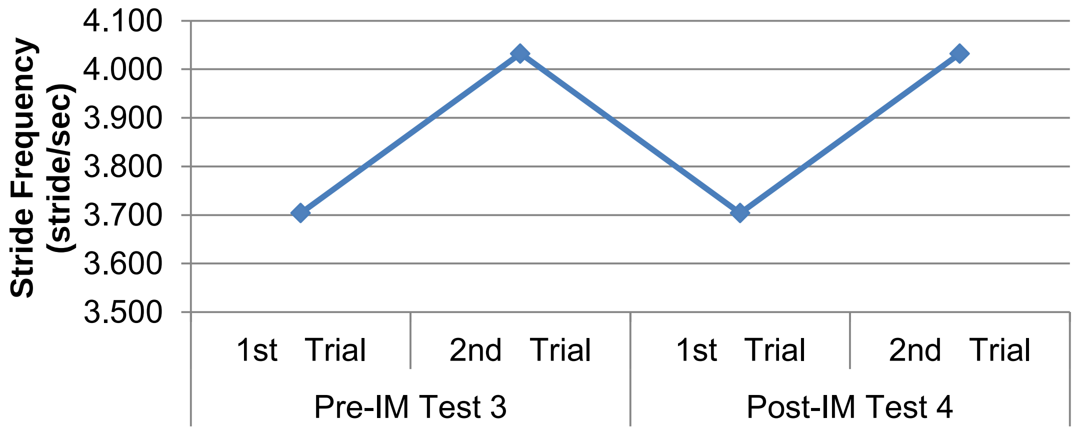


Figure 27. Stride frequency during the maximal speed phase for Participant One from pre- to post-IM™ training

It appears that if IM™ training had any influence on the key performance indicators of the maximal running velocity phase, it would be on increasing stride length, which would have a positive impact on the sprinting time.

Subjective Information Provided by Participant One

During the IM™ intervention period, observations were made and questions were asked by the researcher and Participant One's responses were recorded in order to add context to understanding the potential the impact of IM™ training (Table 7).

Table 7

Subjective and observational log information for Participant One

After 1 week of IM™ training	
Are you feeling more comfortable with the IM training?	Yes
Are you finding that you are becoming more rhythmic in your running?	No
Observations by Researcher	
Instability noticeable on the side of the amputation, causing much frustration and irritation by athlete.	
After 3 weeks of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	Yes
Observations by Researcher	
Noticeable improvement in amputation side stability and overall body control; athlete appears far more comfortable with the IM™ training.	
After completion of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	Yes
Do you feel that this training had a positive effect on your athletic abilities?	Yes
Do you feel that more/longer training on the IM device will be of any benefit?	No
Observations by Researcher	
Athlete appears to really enjoy the training and is noticeably more accurate in his timing; his body movements are more exacting and controlled.	

Summary of the Potential Influence of IM Training on Sprint Kinematics of Participant One

From the subjective information, it can be noted that the athlete did feel an improvement in the rhythm of his running and did feel that the IM™ training had a positive influence on his sprinting performance. However, he did not feel more or longer IM™ training would be beneficial. The researcher perceived improvements in amputation side stability and overall body control, as well as an improvement in the precision with which Participant One performed the various timing tasks.

In terms of sprint kinematics, however, there may have been a positive influence on stride frequency during the initial acceleration phase and on stride length during the maximal running velocity phase. This may indicate a positive area for future research because IM™ training has been associated with improvements in rhythm which could contribute to a faster stride rate and with improvements in coordination which could contribute to taking a longer stride length.

Case Study Two

Participant Two was born in 1985. At the age of 11, she was diagnosed with a condition called Stargardt's Disease. The condition affects the central vision. As a result of her condition, she struggles to see details in the environment and therefore competes as an athlete with a visual impairment in the T13 category. At the age of 15 she began competing in sprinting events and her first elite international competition at 17. Her main events are the 100m, 200m, 400m and long-jump. For her last few world-class events she has been focusing on the 100m and the long jump events. Her personal best in the 100m came in 2008 and is a time of 12.41s.

Variability of the Sprinting Kinematics of Participant Two

Data were collected during four testing sessions distributed throughout the training year. The data are presented to answer the three sub-questions related to variability in her sprinting kinematics.

Variability in the Set Position

The results of the biomechanical analysis of the set position for each of the four test sessions are presented in Table 8. Variability is reported for each of the seven biomechanical features of the set position for Participant Two during each of the four test periods.

The angles she created for her arms demonstrated the largest variability (39.8) over the course of the training year. This could indicate that this athlete's coach had her adjust her starting block placement distance from the line, or that she was changing the placement herself. This might have been so that she could feel more comfortable out of the blocks and to assist her feel more balanced and controlled into her running stride.

Table 8

Results of the biomechanical features during the four tests for Participant Two.

	Pre-Test 1		Pre-Test 2		Pre-IM Test 3		Post-IM Test 4		Mean ± SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial		
Front Ankle	98.9	102.1	101.5	97.5	97.8	98.9	106.6	105	101.0 ± 3.4	11.4
Rear Ankle	100	108.3	98.7	102.3	99	100	105.5	98.9	101.6 ± 3.5	12.6
Front Knee	103.2	100.6	102.3	100.7	100.8	100.7	104.2	102.5	101.9 ± 1.4	1.9
Rear Knee	129	127	126.7	123.7	121.1	129	118	120.2	124.3 ± 4.2	17.8
Rear Hip	52.6	51.6	50.6	54.6	57.6	52.6	50.4	54.3	53.0 ± 2.4	5.7
Trunk	39.9	37.9	38.7	41.3	36.6	39.9	39.9	46.9	40.1 ± 3.1	9.6
Arms	110.5	118.6	114.9	117.6	111.1	119.6	106.2	126.3	115.6 ± 6.3	39.8

Variability during the Initial Acceleration Phase (0-10m)

The following figures (Figures 28 – 32) report the results of the analysis of the key performance indicators during the initial acceleration phase of the sprint for Participant Two over the four testing sessions. A complete table presenting the data collected on the kinematics of this initial acceleration phase is presented in Appendix C.

The relationship between the first two strides out of the blocks and their effect on time is shown in Figure 28. It is noticeable that the first stride out the blocks is variable in length throughout the eight trials. However, the second stride is more consistent and lengthens towards the latter trials, possibly showing that a more balanced start mechanics was found. This may be the key to having an impact on the time for this phase of the sprint.

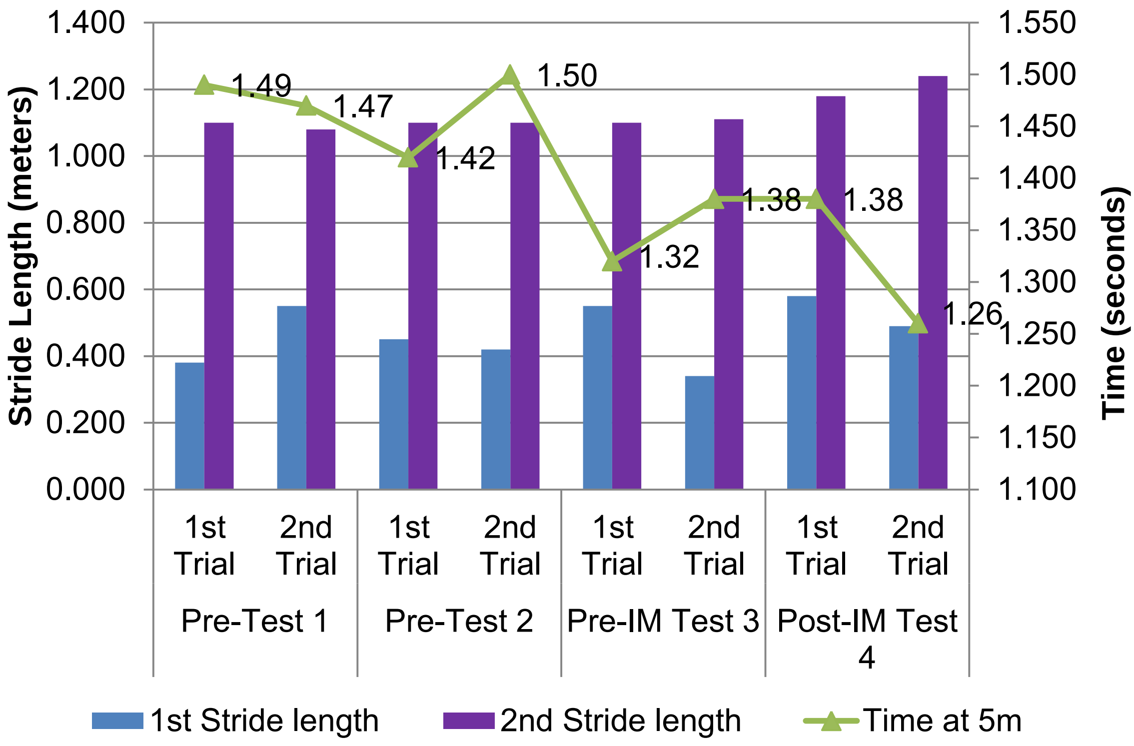


Figure 28. First two stride lengths and time taken during the initial acceleration phase for Participant Two

The role of stride length for this athlete is evident when the kinematics for the third stride through the 10m mark are tracked (Figure 29). It can be seen that her average stride length varied between 1.42m and 1.53m, her stride length is not always related to faster times. In fact, there are time when her stride length shortens and her time is faster (Pre-test 2 Trial 1). When stride length was analysed in relation to speed (Figure 30), the identical pattern is evident. This tells us that the performance of this athlete stride length alone over the first 10m of the sprint is not the critical performance indicator.

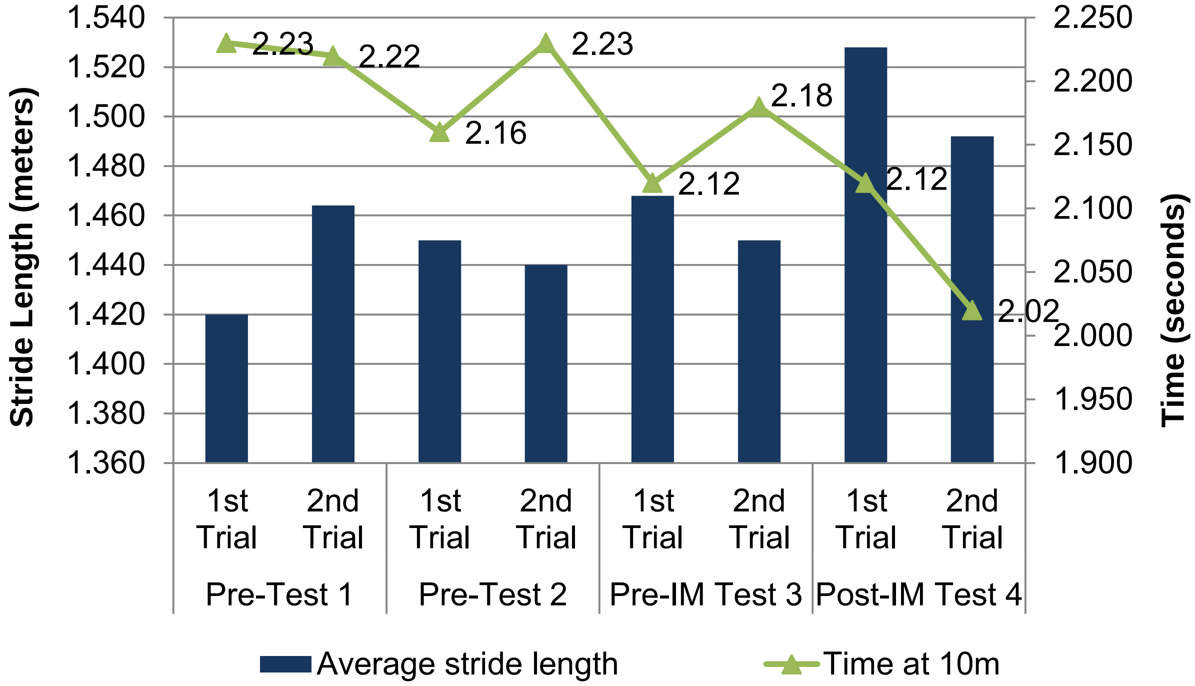


Figure 29. Average stride length (3rd stride to 10m) and time taken during the initial acceleration phase for Participant Two

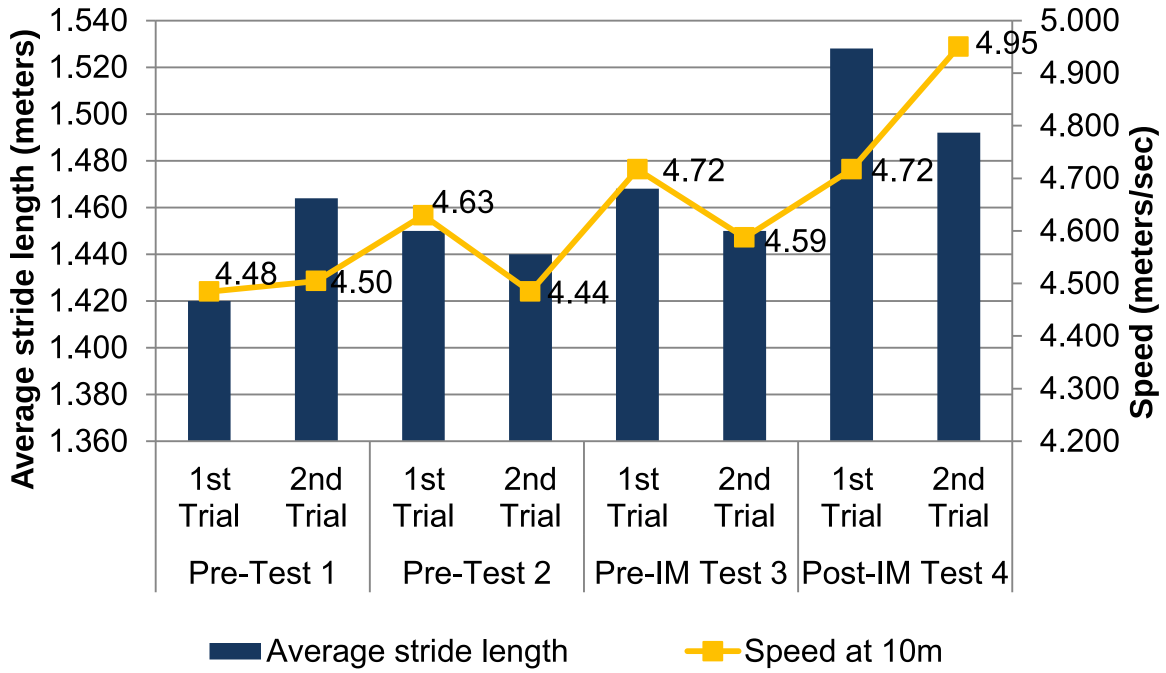


Figure 30. Average stride length (3rd stride to 10m) and speed during the initial acceleration phase for Participant Two

In *Figures 31* and 32, variability in stride frequency is shown in relation to speed for this athlete.

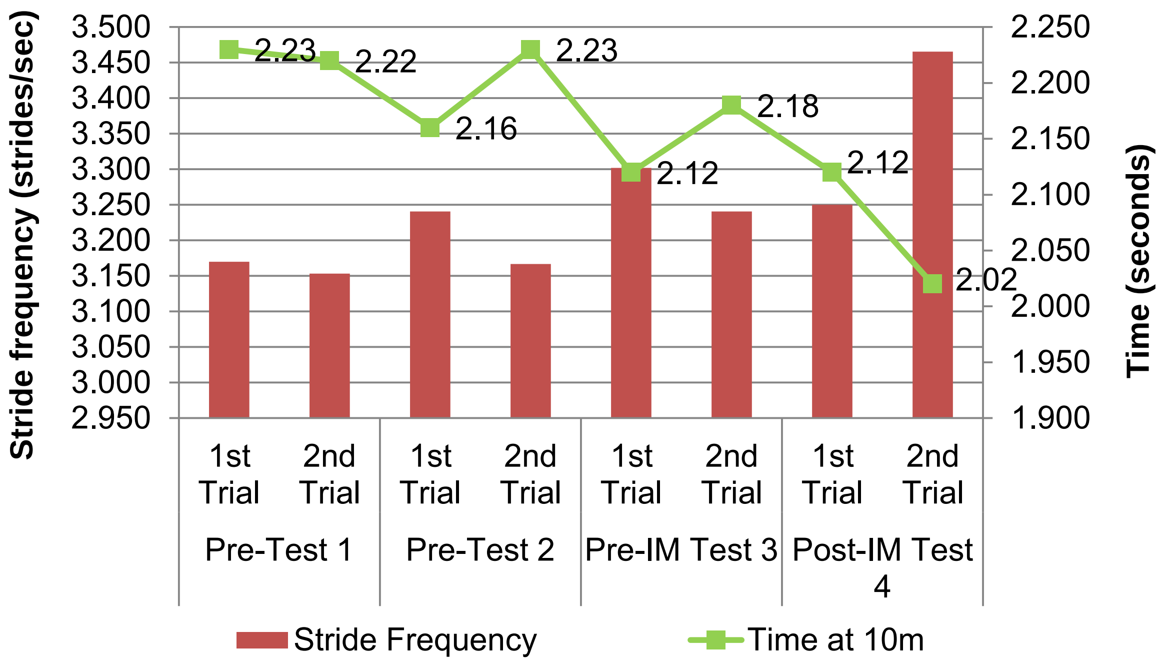


Figure 31. Stride frequency and time taken during the initial acceleration phase for Participant Two

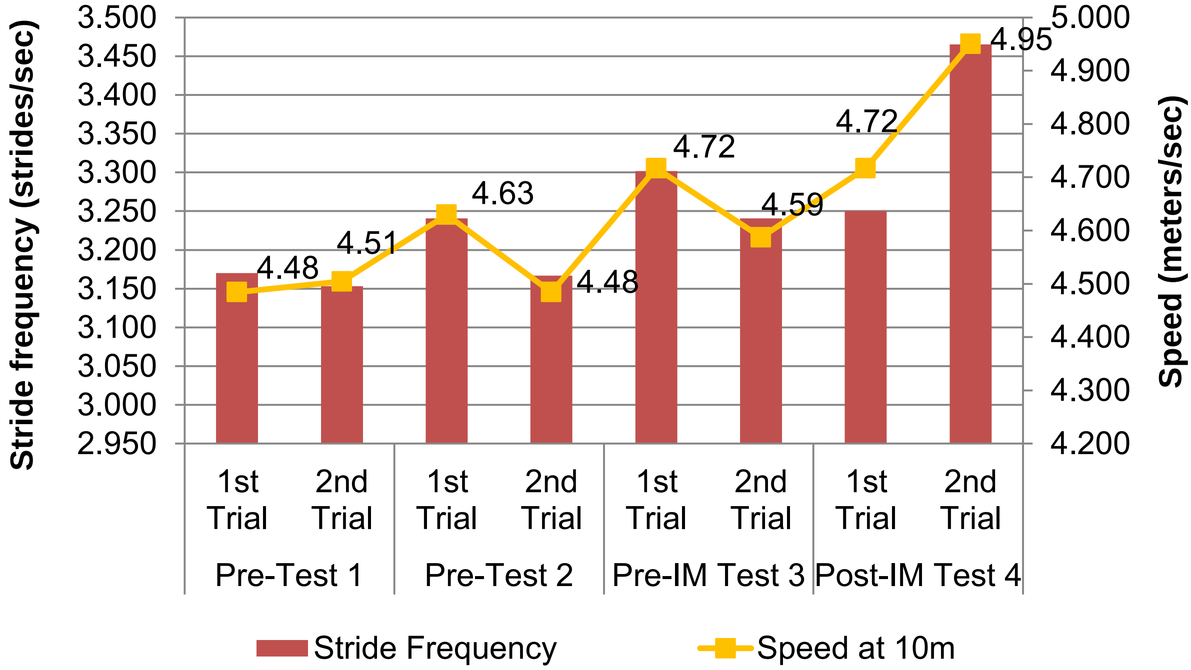


Figure 32. Stride frequency and speed during the initial acceleration phase for Participant Two

There appears to be a clear link between the stride frequency and time and in speed when the third stride to 10m is analysed. Stride frequency varies only between 3.17 and 3.47 strides per second. This would point to stride frequency as the critical focus for this athlete from 0-10m.

The correlation between stride length and stride frequency during the initial acceleration phase is presented in Figure 33. Although the correlation calculation over all four test sessions is not strong (r = 0.51), it can be noted that stride frequency became slightly higher for the first three tests. For both of the trials on Test 1 (circled in red), a lower stride frequency can be noticed and the variability can be attributed to stride length. For the remaining tests, Test 2 (circled green) and Test 3 (circled yellow), a higher stride frequency is seen with a slightly longer stride length on the second trial. On Test 4 (the end training year) the highest rates of stride frequency and average stride length were achieved and the fastest times were recorded. Although this athlete may key off of stride frequency, finding the optimal combination of stride frequency with stride length remains her goal during the initial acceleration phase of the sprint.

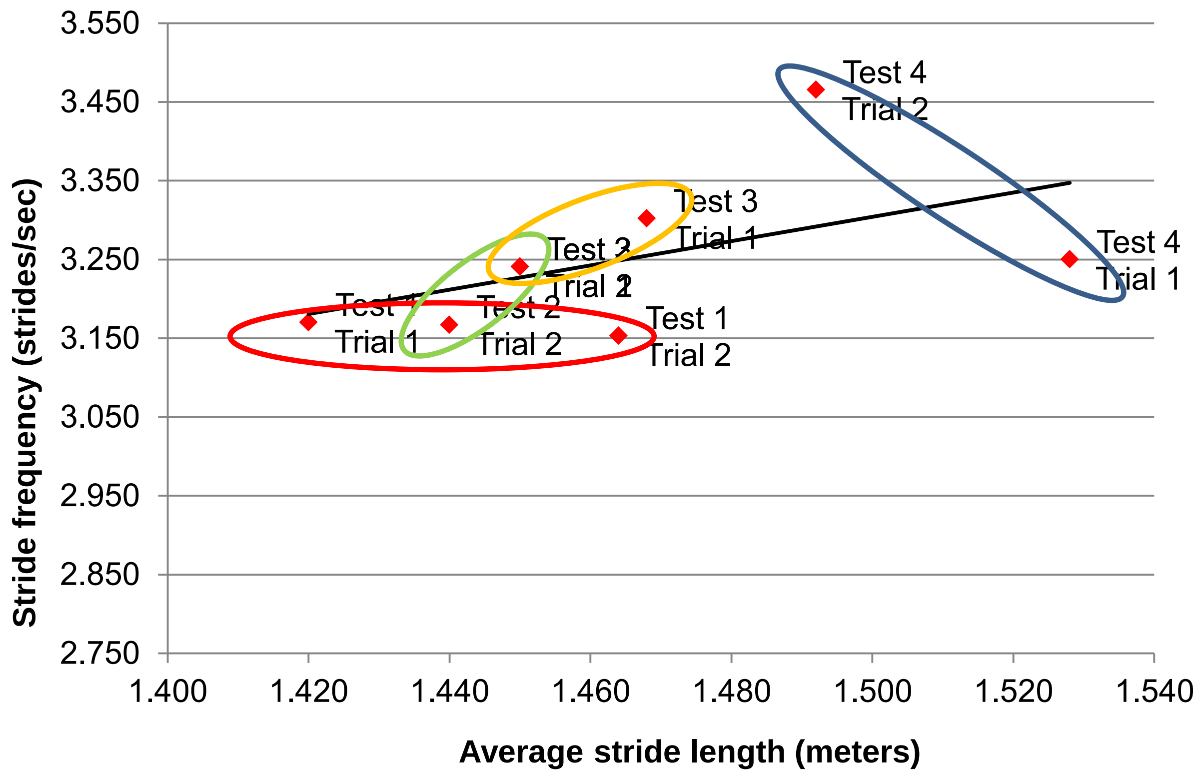


Figure 33. Correlation between stride frequency and stride length during the initial acceleration phase for Participant Two

Variability during the Maximal Running Velocity Phase (30m-40m)

The following figures (Figures 34 – 37) report the results of the analysis of the key performance indicators during the maximal running velocity phase of the sprint for Participant Two over the four testing sessions. A complete table presenting the data collected on the kinematics of this phase is presented in Appendix C.

Stride length from the 30m to the 40m mark was inconsistent over the training year (Figure 33), but it can be observed that in general, stride length was shortened. The athlete's time over these 10m was quite consistent with the exception of the Test 3, which was noticeably slower. The athlete ran her fastest in Test 4 and in Trial 2 (1.2s) with her shortest stride length (1.89m). The effect of stride length on speed is reflected in Figure 35 which documents the change in speed from 8.07 m/sec to 8.33 m/s from the beginning to end of the year.

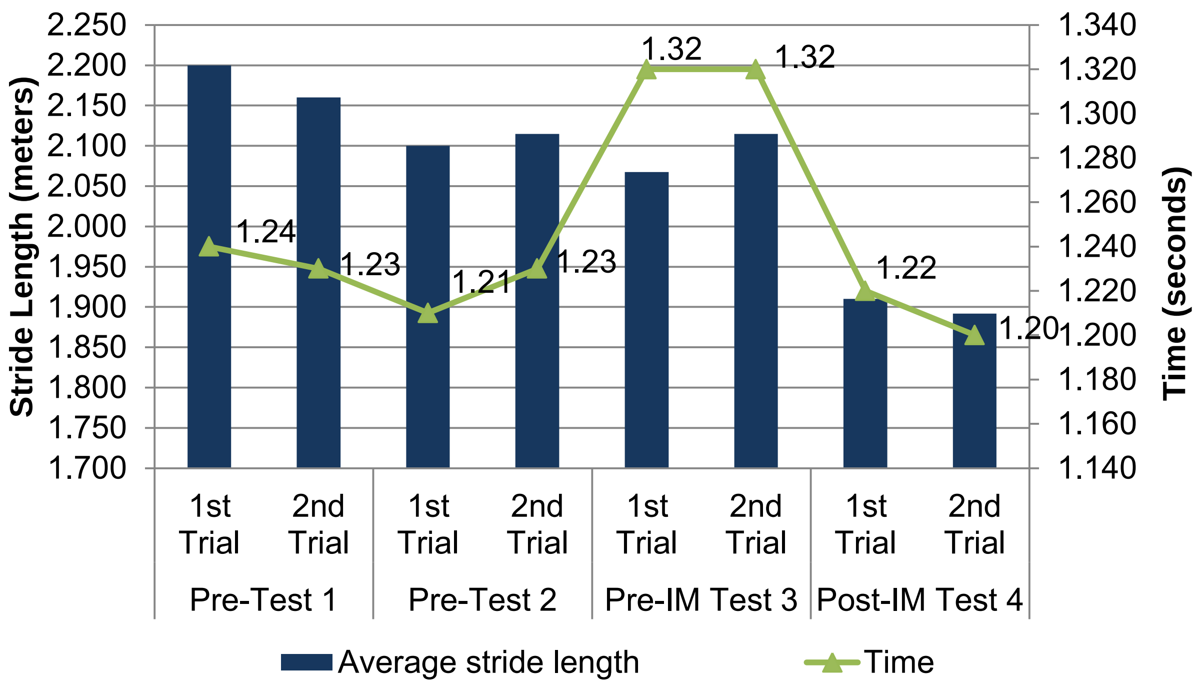


Figure 34. Average stride length and time taken during the maximal running velocity phase for Participant Two

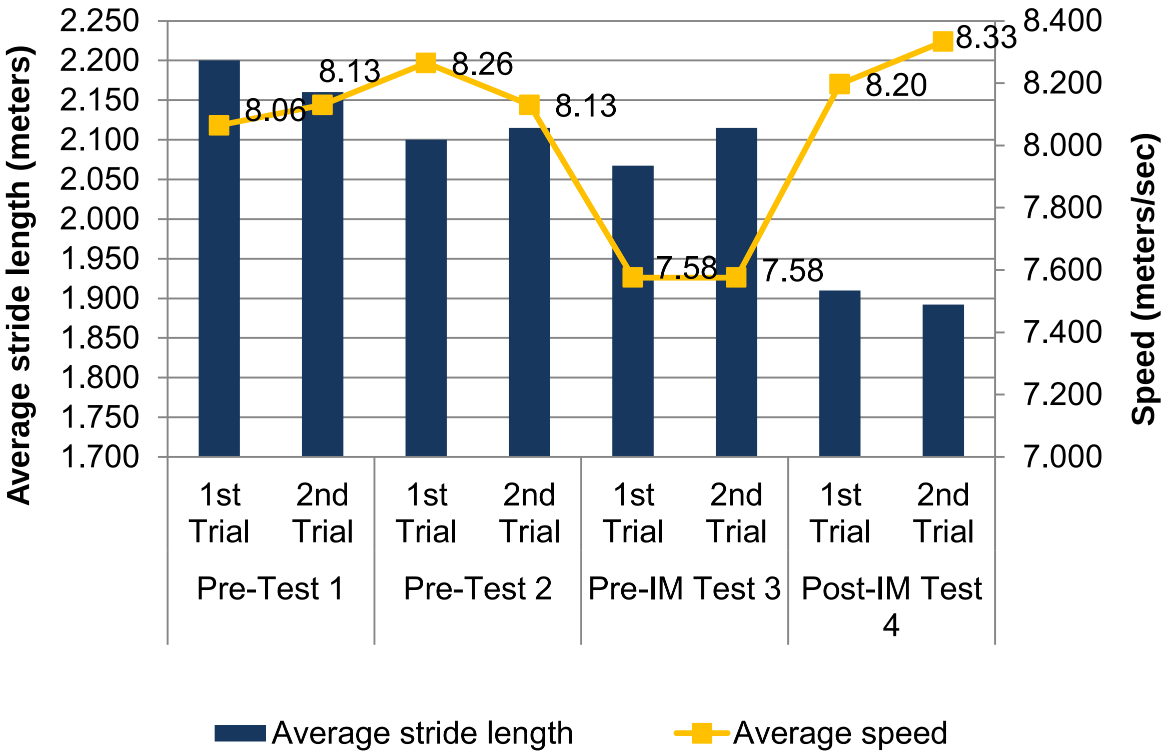


Figure 35. Average stride length and the speed during the maximal running velocity phase for Participant Two

When stride frequency from the 30m to the 40m mark is compared to time (Figure 36) and to speed (Figure 37), this athlete fluctuated between 3.78 to 4.27 strides/sec (a difference of 0. 49 stride/sec) over the course of the training year. It does appear that time and speed are linked to stride frequency for this athletes, with time decreasing as stride frequency increased and vice versa, and speed increasing as stride frequency increased and vice versa.

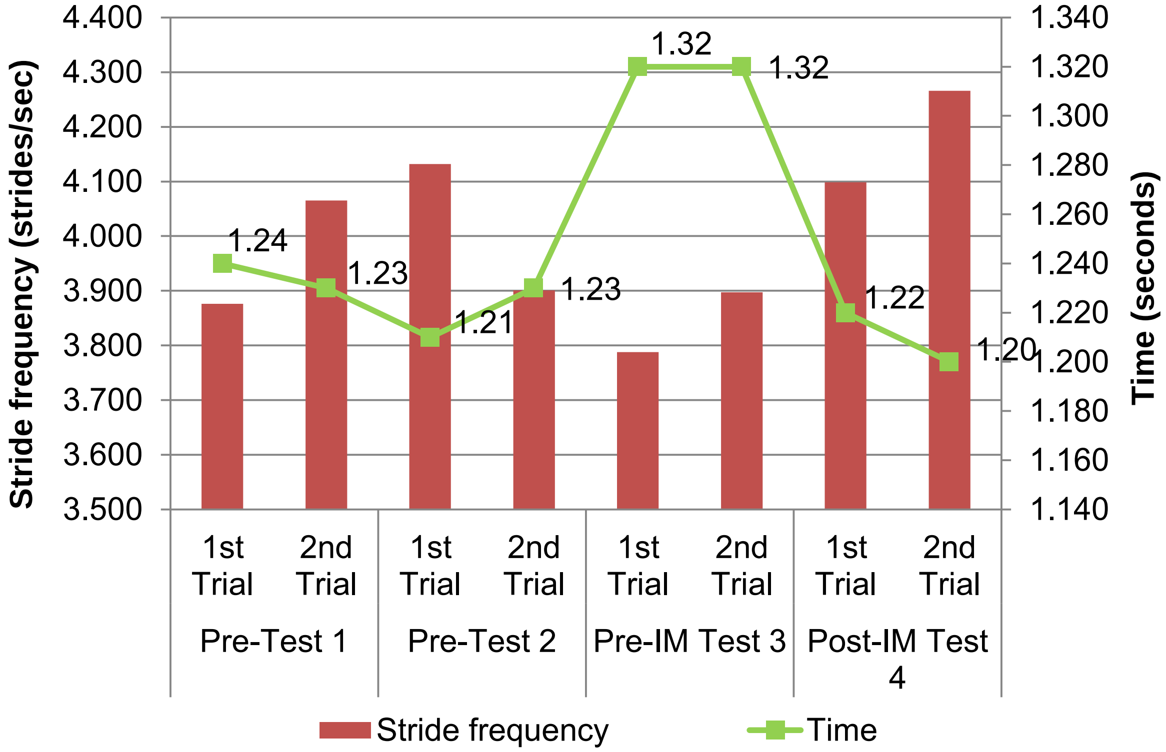


Figure 36. Stride frequency and the time taken during the maximal running velocity phase for Participant Two

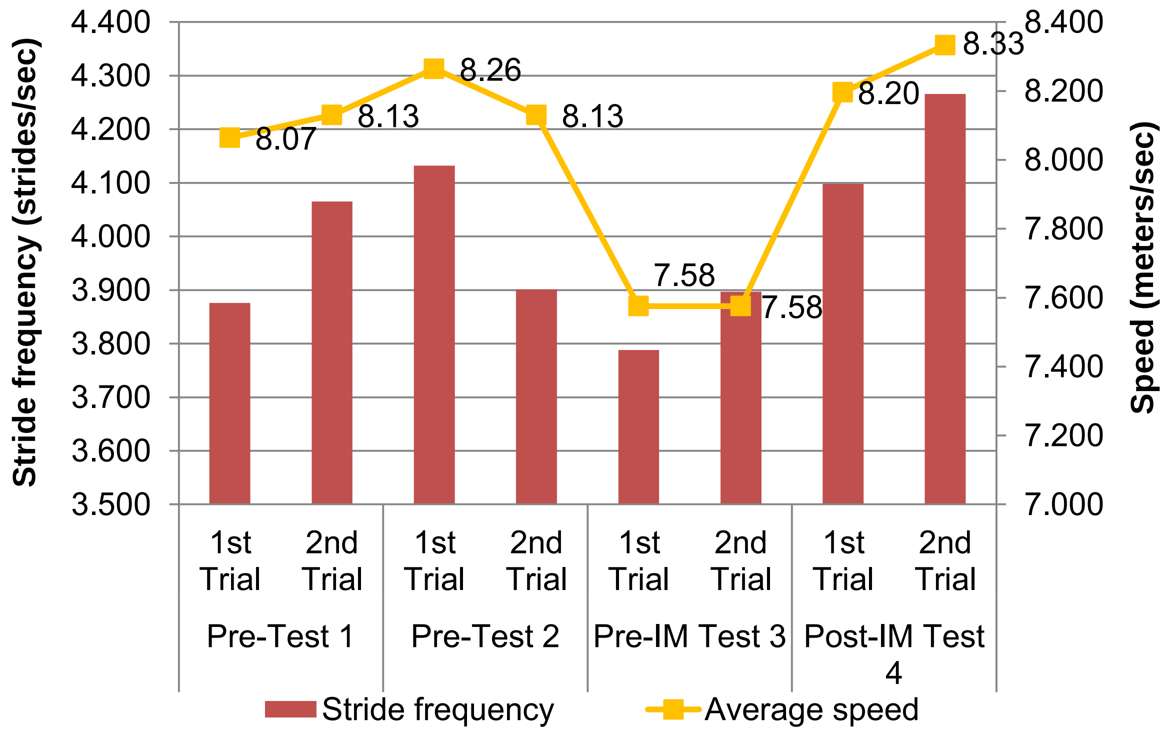


Figure 37. Stride frequency and the speed during the maximal running velocity phase for Participant Two

The correlation between stride frequency and stride length during the maximal running velocity phase was plotted (Figure 38) and found to have a very fairly strong correlation (r = 0.79). The following can be noted:

- The average stride length from Test 1 (circled red) to Test 4 (circled blue) decreased steadily while the stride frequency tended to increase.
- Stride length progressively decreased throughout the training year (2.20m to 1.89m), while stride frequency increased and appears to be the key performance indicator for this athlete’s speed. The progressive increase in stride frequency (from 3.78 strides/sec to 4.27 strides/sec) supports the focus on stride frequency as the key to this athletes speed. The optimal relationship with stride length was found by shortening the stride length and increasing stride frequency.

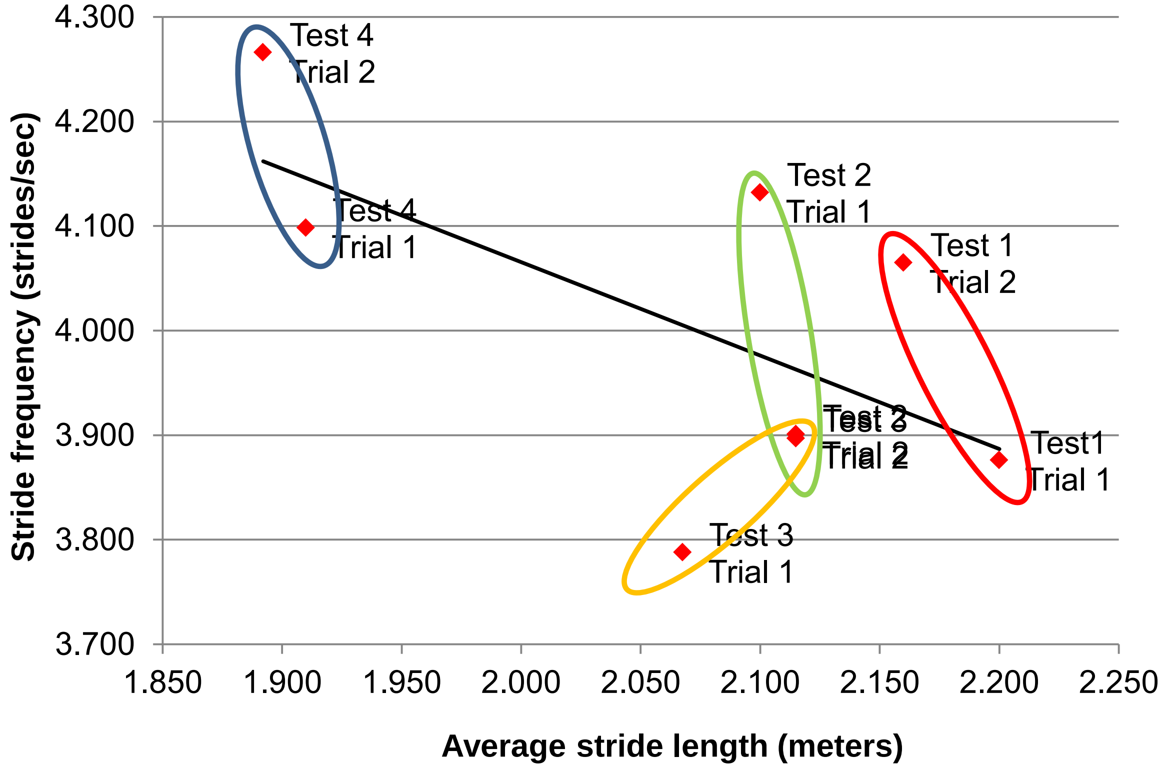


Figure 38. Correlation between stride frequency and average stride length during the maximal running velocity phase for Participant Two

Summary of the Variability Observed in the Sprinting Kinematics of Participant Two

Summary: Variability in the Set Position

The angles she created for her arms demonstrated the largest variability (39.8) over the course of the training year. This could indicate that this athlete's coach had her adjust her starting block placement distance from the line, or that she was changing the placement herself. Being an athlete with a visually impairment it is even more important for her to try and exit the blocks in a balanced, rhythmic manner. By her adjusting the position of the blocks (further forward, decreasing the angle, or back, increasing the angle) she might feel more comfortable out of the blocks and to assist her feel more balanced and controlled into her running stride.

Summary: Variability during the Initial Acceleration Phase (0-10m)

This athlete's first stride out the blocks is variable in length throughout the eight trials, while their second stride is more consistent and even lengthens towards the latter trials coinciding with improvements in performance. This possibly shows that a more balanced start mechanics, with a shorter first stride and longer second stride, may be the key to having an impact on the performance for this phase of the sprint

This athlete's average stride length varied between 1.42m and 1.53m. This athlete does not seem to have a direct link between stride length and time as the stride length and the time and are not consistently inversely linked. This lack of a set pattern was mirrored when stride length was analysed in relation to speed. In this phase of the sprint, stride length does not appear to be the key performance indicator. This athlete's stride frequency varies between 3.17 and 3.47 strides per second. Stride frequency does appear to be related to time and speed from the third stride to 10m. This may indicate that for this athlete in this phase of the sprint, stride frequency is the key performance indicator.

The correlation between stride length and stride frequency over all four test sessions is not strong ($r = 0.51$). This supports the observation that the athlete can go faster either by increasing stride frequency or stride length, although fastest times are achieved with the highest stride frequencies.

Summary: Variability during the Maximal Running Velocity Phase (30m-40m)

Stride length for this athlete was inconsistent over the training year. The athlete's performed best at the end of the training year despite having the lowest stride length at this stage (1.89m). This would tend to indicate that, for this athlete, stride length is not the key performance indicator. Stride frequency for this athlete only fluctuated between 3.78 to 4.27 strides/sec (a difference of 0.49 stride/sec) over the course of the training year. Stride frequency appears to be the key performance indicator for this athlete in this phase of the sprint.

The correlation between stride frequency and stride length during the maximal running velocity phase was found to have a very fairly strong correlation (r = 0.79). Stride length progressively decreased throughout the training year (2.20m to 1.89m), while stride frequency increased (from 3.78 to 4.27 strides/sec) and appears to be the key performance indicator for this athlete's speed. The progressive increase in stride frequency supports its critical role as a focus for coaching.

The Potential of Interactive Metronome Training™ to Influence the Sprinting Performance of Participant Two

Participant Two was actively involved in the Interactive Metronome Training™ programme during the period between Test Session 3 (Pre-IM training) and Test Session 4 (Post-IM training). A comparison between her pre-test and post-test scored on IM precision timing is presented in Figure 39. It can be seen that there was an improvement in the millisecond accuracy following the intervention period on tasks for the hands only, feet only, left side of body, right side of body and bilateral. Table 9 presents the total summary for all task repetitions (3995) in the programme, and indicates that Participant Two achieved a 32.4% improvement in the precise timing of her movements after completing the intervention programme.

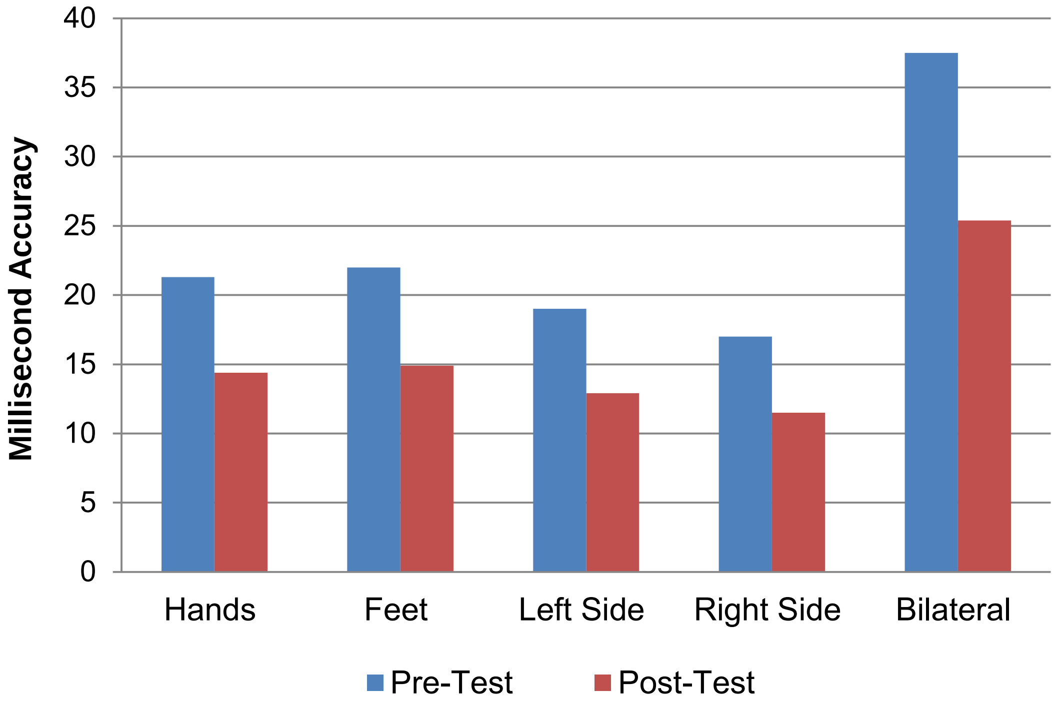


Figure 39. Millisecond accuracy improvements from the pre-test evaluation to the post-test evaluation in the IM training

Table 9

Pre- and post-test adjustment values and improvement following IM™ training for Participant Two.

Total Repetitions	Pre-Test Adjusted Value	Post-Test Adjusted Value	Pre- to Post- Test Improvement
3995	32.00	21.60	32.40%

Any signs of possible influence of IM™ training on the sprinting performance of Participant Two would have to be found in the differences in the sprint kinematics reported for Pre-IM Test 3 and Post-IM Test 4. The presentation of this data in the following figures is limited to the performance indicators of time, stride length and stride frequency in order to make this comparison clear.

The Potential Influence of IM™ training on the Sprinting Kinematics of Participant Two during the Initial Acceleration Phase (0-10m)

The following trends can be noted after the IM training for three of the key performance indicators during the initial acceleration phase:

- Time decreased slightly - the participant ran faster (Figure 40).
- Stride length increased slightly (Figure 41).
- Stride frequency increased (Figure 42).

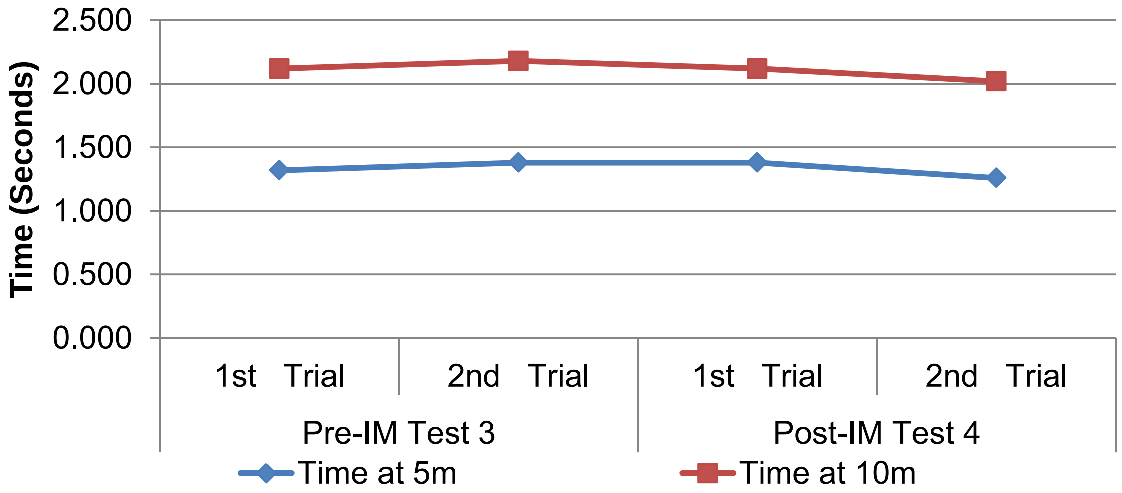


Figure 40. Time at 5m and 10m during the initial acceleration phase for Participant Two from pre- to post- IM™ training

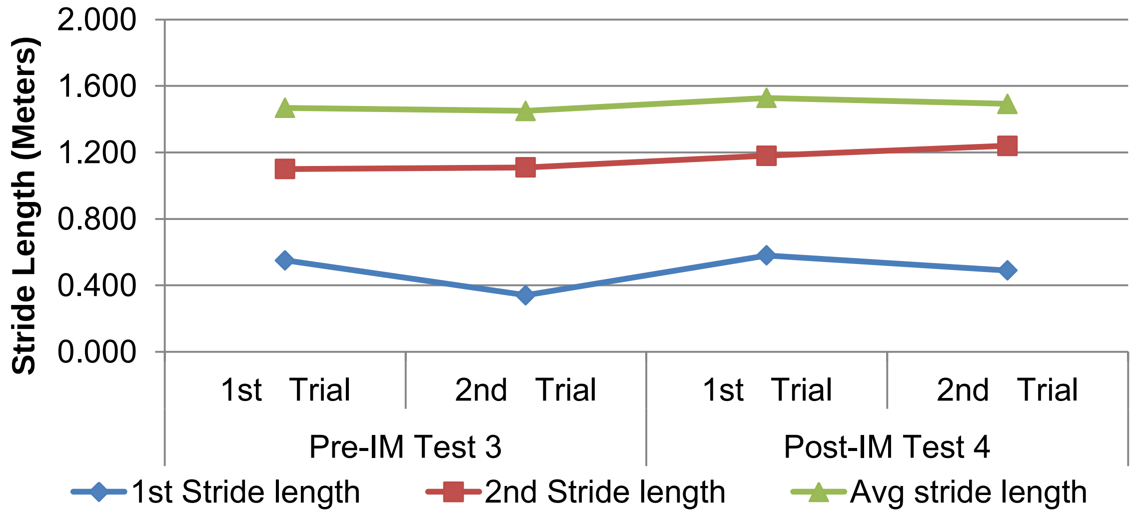


Figure 41. Stride length during the initial acceleration phase for Participant Two from pre- and post-IM™ training

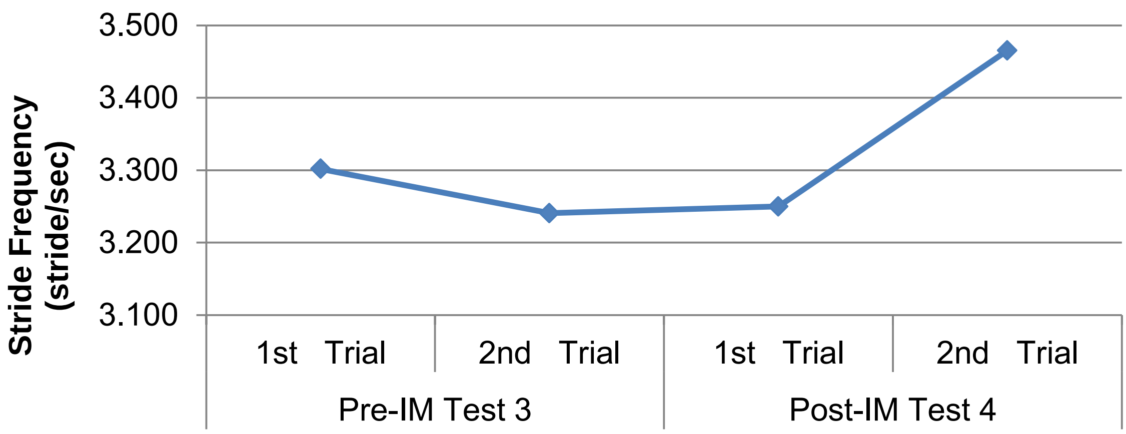


Figure 42. Stride frequency during the initial acceleration phase for Participant Two from pre- to post-IM™ training

If IM™ training had any influence on the initial acceleration phase, it would be on increasing stride frequency, which would have a positive impact on time.

The Potential Influence of IM™ Training on the Sprinting Kinematics of Participant Two during the Maximal Running Velocity Phase (30m-40m)

The following trends can be noted after the IM training for three of the key performance indicators during the maximal running velocity phase:

- Time decreased - the participant ran faster (Figure 43).
- Stride length decreased (Figure 44).
- Stride frequency increased (Figure 45).

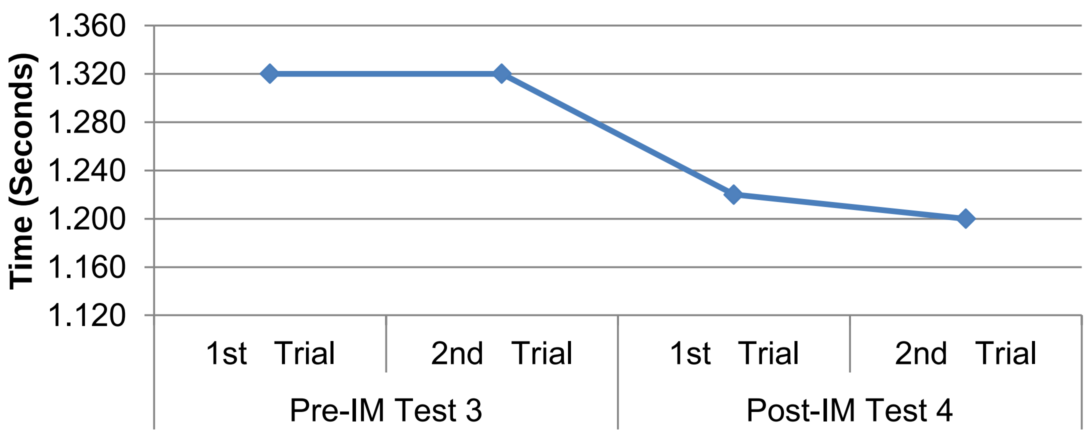


Figure 43. Time during the maximal running velocity phase for Participant Two from pre- to post-IM™ training

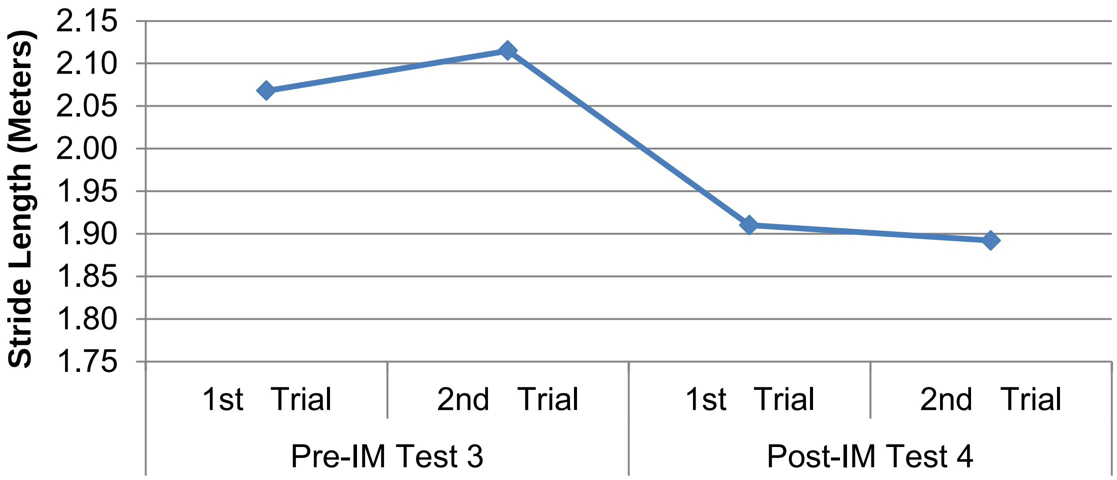


Figure 44. Stride length during the maximal speed phase for Participant Two from pre- to post-IM™ training

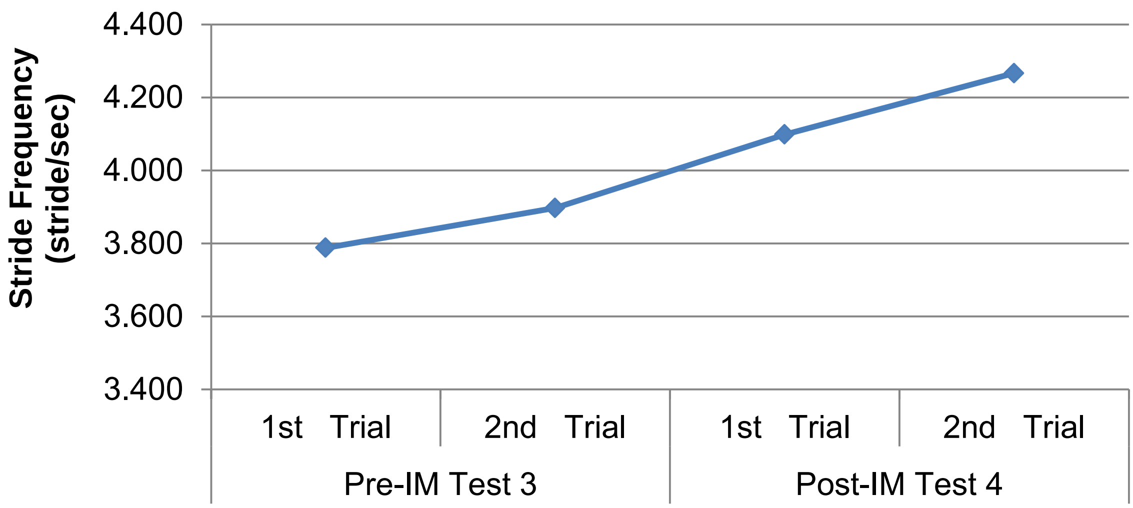


Figure 45. Stride frequency during the maximal speed phase for Participant Two from pre- to post-IM™ training

It appears that if IM™ training had any influence on the key performance indicators of the maximal running velocity phase, it would be on decreasing stride length and increasing stride frequency, which had a positive impact on the sprinting time.

Subjective Information Provided by Participant Two

During the IM™ intervention period, observations were made and questions were asked by the researcher and Participant Two's responses were recorded in order to add context to understanding the potential the impact of IM™ training (Table 10).

Table 10

Subjective and observational log information for Participant Two

After 1 week of IM™ training	
Are you feeling more comfortable with the IM training?	Yes
Are you finding that you are becoming more rhythmic in your running?	No
Observations by Researcher	
Good movements from start for general exercises, however once there was auditory and visual feedback from her performance she got very confused and disorientated, causing much frustration and irritation.	
After 3 weeks of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	No
Observations by Researcher	
Started to become comfortable with the dual feedback, however it still noticeably affected her overall performance and frustration levels.	
After completion of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	Yes
Do you feel that this training had a positive effect on your athletic abilities?	Yes
Do you feel that more/longer training on the IM device will be of any benefit?	No
Observations by Researcher	
Finally seemed to interpret the dual feedback and adjust her movements and rhythm accordingly.	

Summary of the Potential Influence of IM Training on Sprint Kinematics of Participant Two

From the subjective information, it can be noted that the athlete did feel an improvement in the rhythm of her running and did feel that the IM™ training had a positive influence on her sprinting performance but only towards the end of the training year. However, she did not feel that more or longer IM™ training would be beneficial. The researcher observed improvements her ability to perceive information from more than one source and that her overall body movements became more rhythmical, as well as improvements in the precision with which Participant Two performed the various timing tasks.

In terms of sprint kinematics, however, there may have been a positive influence on stride frequency during the initial and maximal running velocity phase. This may indicate a positive area for future research because IM™ training has been associated with improvements in rhythm and balance, which could contribute to a faster stride rate and with improvements in bilateral coordination when sprinting.

Case Study Three

Participant Three was born in 1986 and early in his developmental years, it became evident that he had cerebral palsy. This did not stop him and he committed himself to finishing his schooling and then went on to a tertiary institution where he completed his degree.

Whilst completing his degree he started to compete in athletics, which he had done at school, but now with more drive and commitment. In 2006 he started to compete at sprinting, in the elite level in his disability class T37. His specialist events are the 100m and 200m. In 2012 he set his personal best in the 100m of 11.51s and in his 200m of 23.67s.

Variability of the Sprinting Kinematics of Participant Three

Data were collected during four testing sessions distributed throughout the training year. The data are presented to answer the three sub-questions related to variability in his sprinting kinematics.

Variability in the Set Position

The results of the biomechanical analysis of the set position for each of the four test sessions are presented in Table 11. Variability is reported for each of the seven biomechanical features of the set position for Participant Three during each of the four test periods.

The angles he created for both his ankles (front = 61.06 and rear = 180.54) along with both knees (front = 51.13 and rear = 28.77) and even rear hip (16.57) demonstrated the large variability over the course of the training year. This could indicate that this athlete’s coach adjusted his start setup and mechanics or he has because he has not been comfortable with the setup. This might have been so that he could feel more comfortable out of the blocks and to assist him feel more balanced and controlled into his running stride.

Table 11

Results of the biomechanical features during the four tests for Participant Three.

	Pre-Test 1		Pre-Test 2		Pre-IM Test 3		Post-IM Test 4		Mean ± SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial		
Front Ankle	90.5	93.2	90.1	92.7	111.3	107	96.2	97.5	97.3 ± 7.8	61.06
Rear Ankle	109.5	108.6	91.3	108.7	98.7	125.6	127.5	126.3	112.0 ± 13.4	180.54
Front Knee	101.6	96.4	101.3	93.4	96.2	96.6	83	83.6	94.0 ± 7.15	51.13
Rear Knee	92.4	93.7	87.6	92.4	95.2	105.4	97.3	99.4	95.4 ± 5.36	28.77
Rear Hip	51.2	59.8	60.3	62.7	63.6	61.3	61.8	64	60.6 ± 4.07	16.57
Trunk	26.4	24.6	23.4	21.7	26.4	25.8	19.9	20.6	23.6 ± 2.61	6.84
Arms	102.1	103.4	98.6	99.8	97.3	102.5	98.2	100.2	100.3 ± 2.21	4.89

Variability during the Initial Acceleration Phase (0-10m)

The following figures (Figures 46 – 50) report the results of the analysis of the key performance indicators during the initial acceleration phase of the sprint for Participant Three over the four testing sessions. A complete table presenting the data collected on the kinematics of this initial acceleration phase is presented in Appendix C.

The relationship between the first two strides out of the blocks and their effect on time is shown in Figure 46. It is noticeable that the first stride out the blocks is quite stable in length throughout the eight trials, only fluctuating by 0.22m throughout the training year. His second stride was also stable in length fluctuating by only 0.17m throughout the training year. With this in mind it does not appear that the stride length is a key performance indicator for this phase of the sprint.

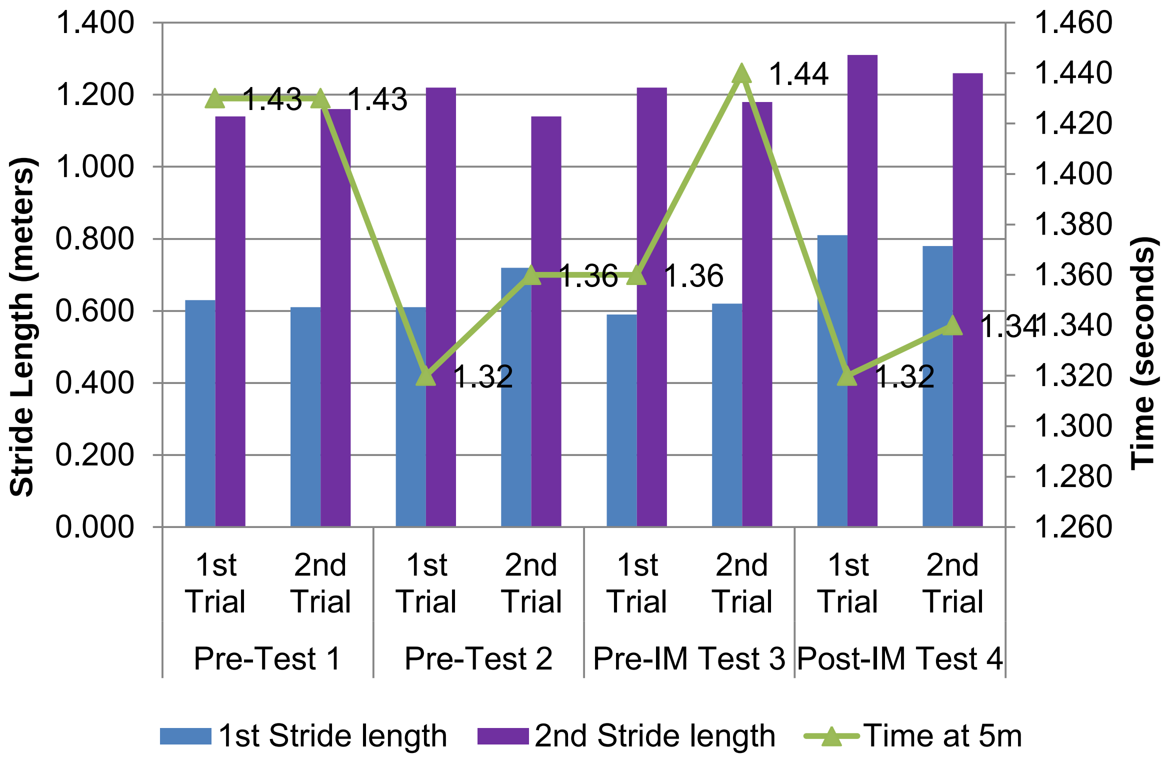


Figure 46. First two stride lengths and time taken during the initial acceleration phase for Participant Three

The critical role of stride length for this athlete is again evident when the kinematics for the third stride through the 10m mark are analysed. In In Figure 47, it can be seen that the average stride length for this athlete varied between 1.502m and 1.590m (difference of only 0.088m). This athlete does seem to have a link between stride length and time as when stride length increases the time tends to drop, and vice versa. This pattern was mirrored when stride length was analysed in relation to speed (Figure 48), as stride length increased so did his speed. This tells us that the stride length is a performance indicator of this athlete during the first 10m of the sprint.

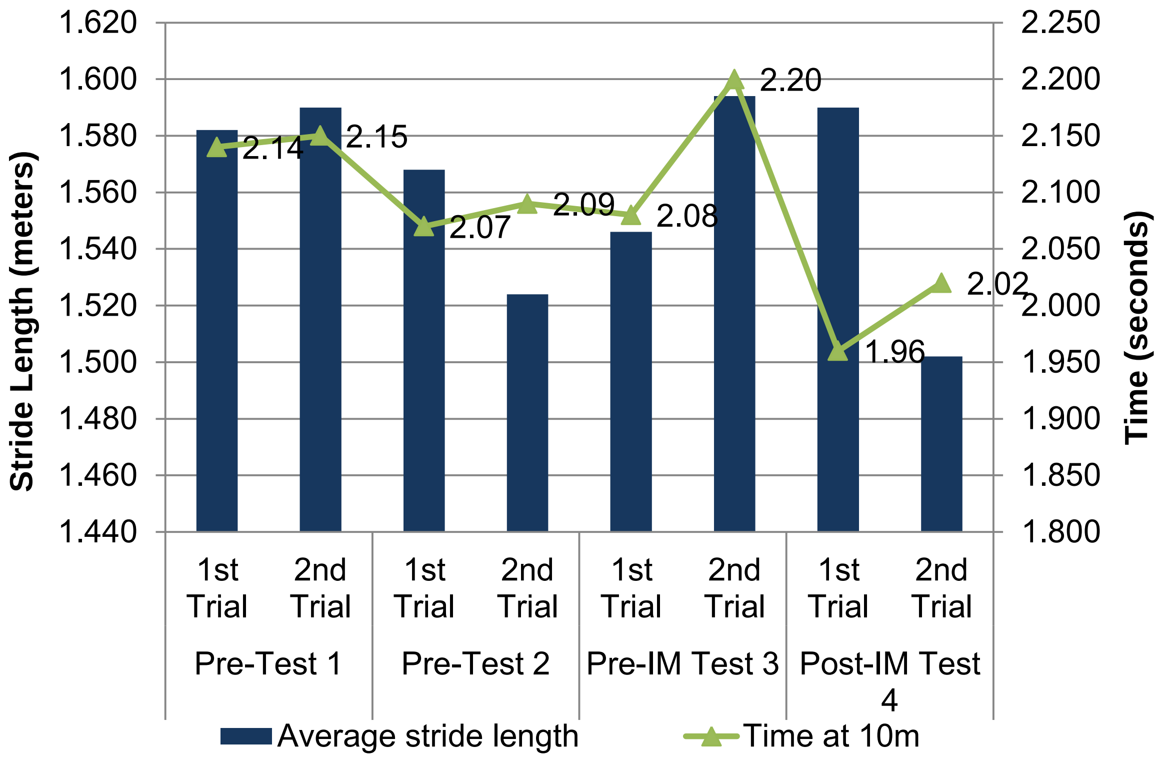


Figure 47. Average stride length (3rd stride to 10m) and time taken during the initial acceleration phase for Participant Three

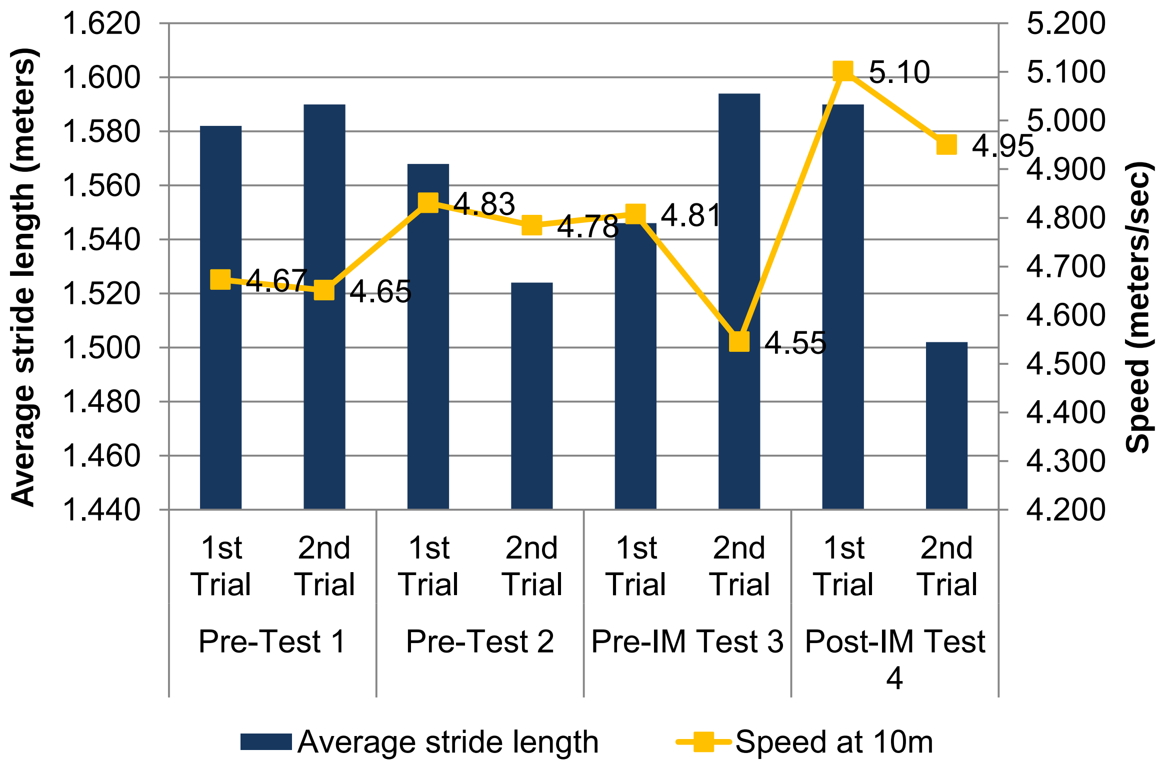


Figure 48. Average stride length (3rd stride to 10m) and speed during the initial acceleration phase for Participant Three

In *Figures 49* and *50*, variability in stride frequency is shown in relation to the time and speed for this athlete. There appears to be a link between the stride frequency and both time and speed. Stride frequency varies only between 3.22 and 3.57 strides per second.

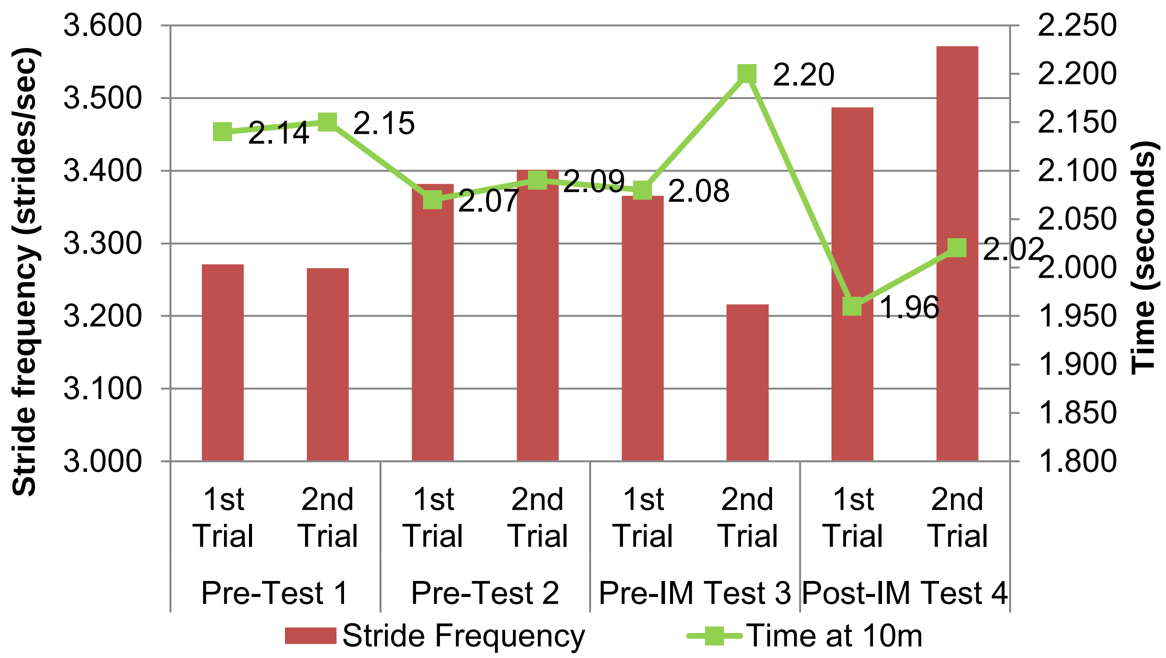


Figure 49. Stride frequency and time taken during the initial acceleration phase for Participant Three

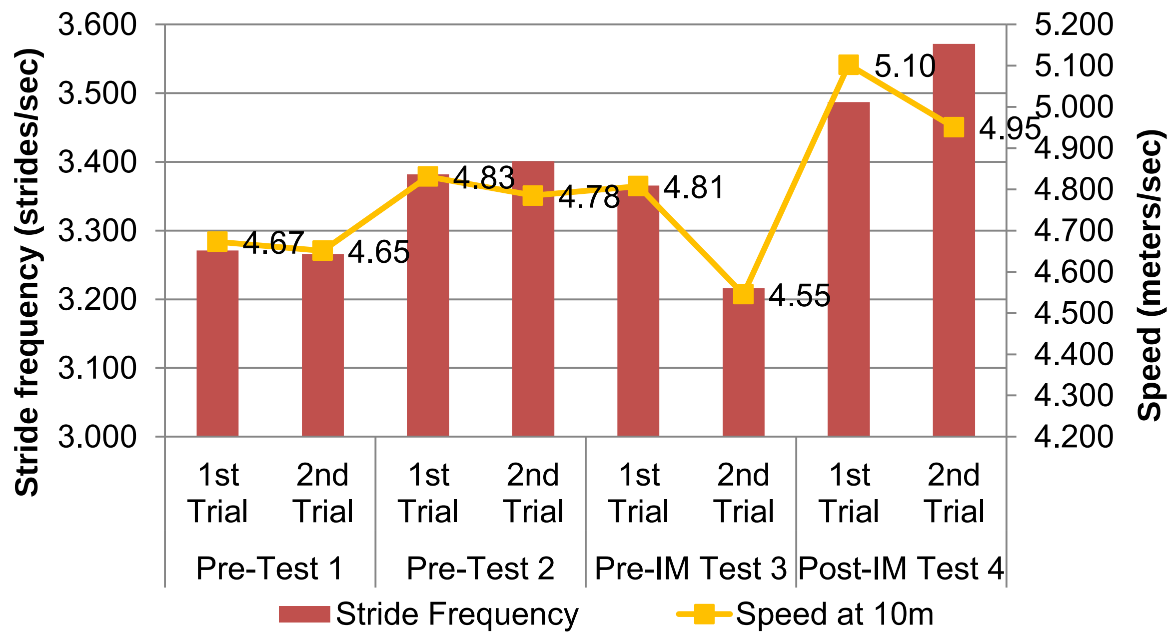


Figure 50. Stride frequency and speed during the initial acceleration phase for Participant Three

The correlation between stride length and stride frequency during the initial acceleration phase is presented in Figure 51. Although the correlation calculation over all four test sessions is not strong (r = 0.68), it can be noted that stride frequency was higher at the end of the training year (circled blue). For both of the trials on Test 1 (the beginning of the training year, circled in red), a lower stride frequency can be noticed and a higher stride length, this was also when the slowest performances were recorded. During the Test 2 (circled green) and Test 3 (circled yellow), moderate levels of stride frequency and stride length are achieved. All this information suggests that for this athlete stride frequency appears to be the key performance indicator during the initial acceleration phase of the sprint.

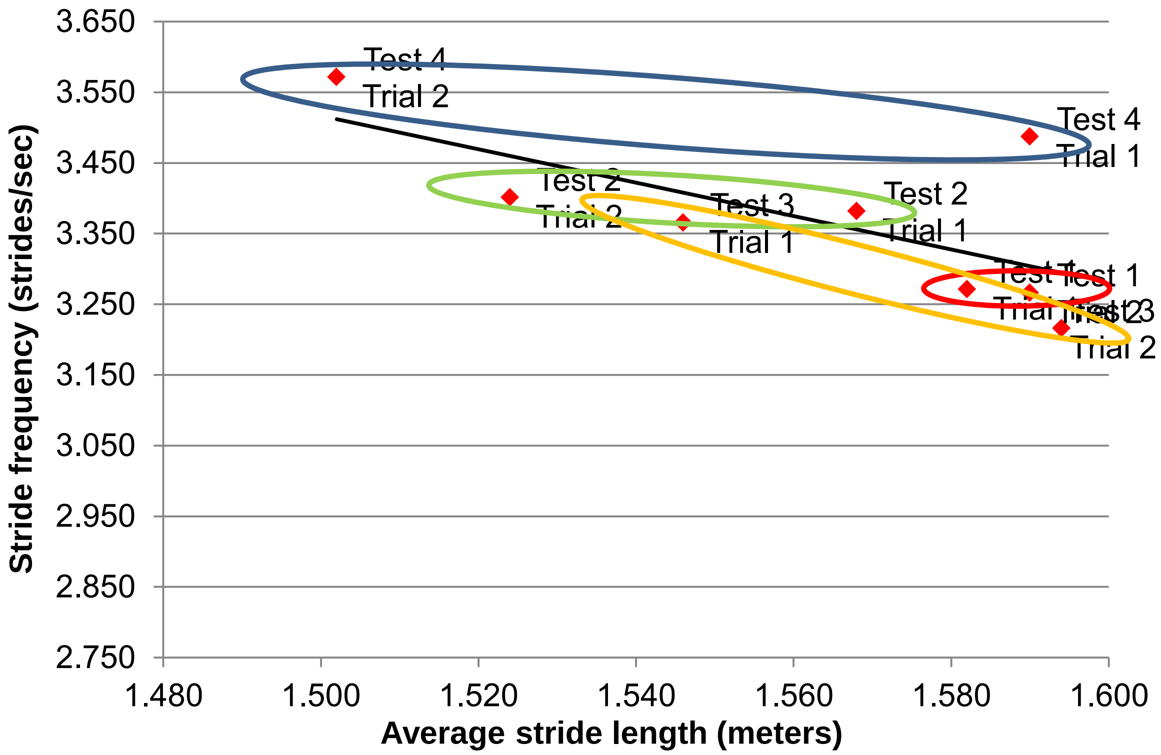


Figure 51. Correlation between stride frequency and stride length during the initial acceleration phase for Participant Three

Variability during the Maximal Speed Phase (30m-40m)

The following figures (Figures 52 – 55) report the results of the analysis of the key performance indicators during the initial acceleration phase of the sprint for Participant Two over the four testing sessions. A complete table presenting the data collected on the kinematics of this maximal acceleration phase is presented in Appendix C.

Stride length from the 30m to the 40m mark was inconsistent over the training year (Figure 52). The athlete's time over these 10m did improve through the training year with the athlete running fastest in Test 4 and in Trial 2 (1.06s), however the times were very fluctuating. This fastest trial coincides with the largest stride length at this stage (2.098m). The effect of stride length on speed is reflected in Figure 53 which documents the change in speed from 7.35 m/sec to 9.43 m/s over the course of the training year.

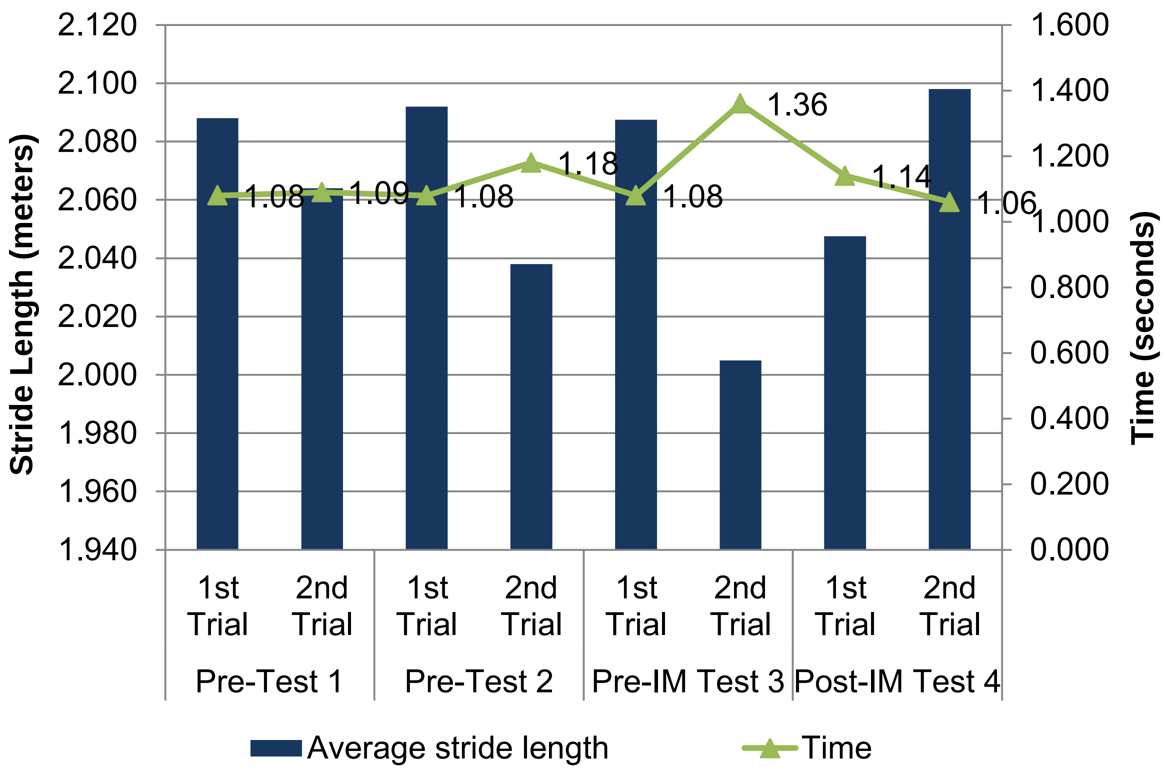


Figure 52. Average stride length and time taken during the maximal speed phase for Participant Three

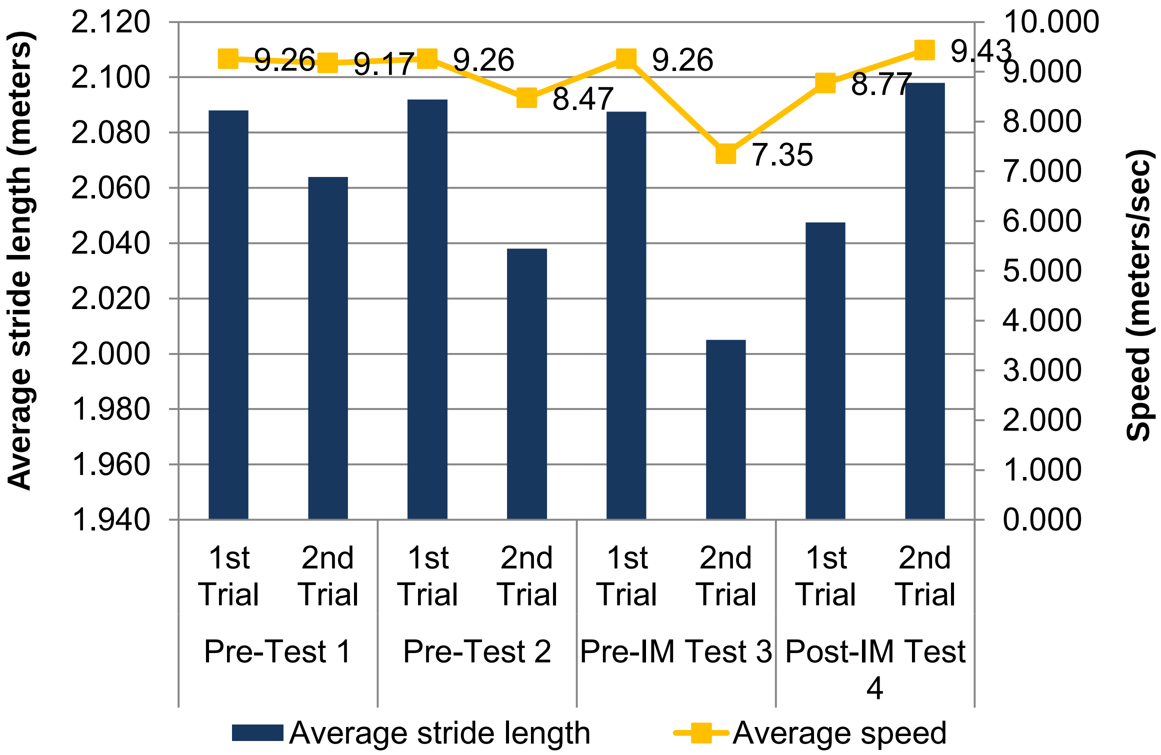


Figure 53. Average stride length and the speed during the maximal speed phase for Participant Three

When stride frequency from the 30m to the 40m mark is compared to time (Figure 54) and to speed (Figure 55), this athlete only fluctuated between 3.42 to 3.77 strides/sec (a difference of only 0.35 stride/sec) over the course of the training year. Both time and speed appear to be closely linked to stride frequency with time decreasing as stride frequency increase and vice versa; while speed increased as stride frequency increased and vice versa.

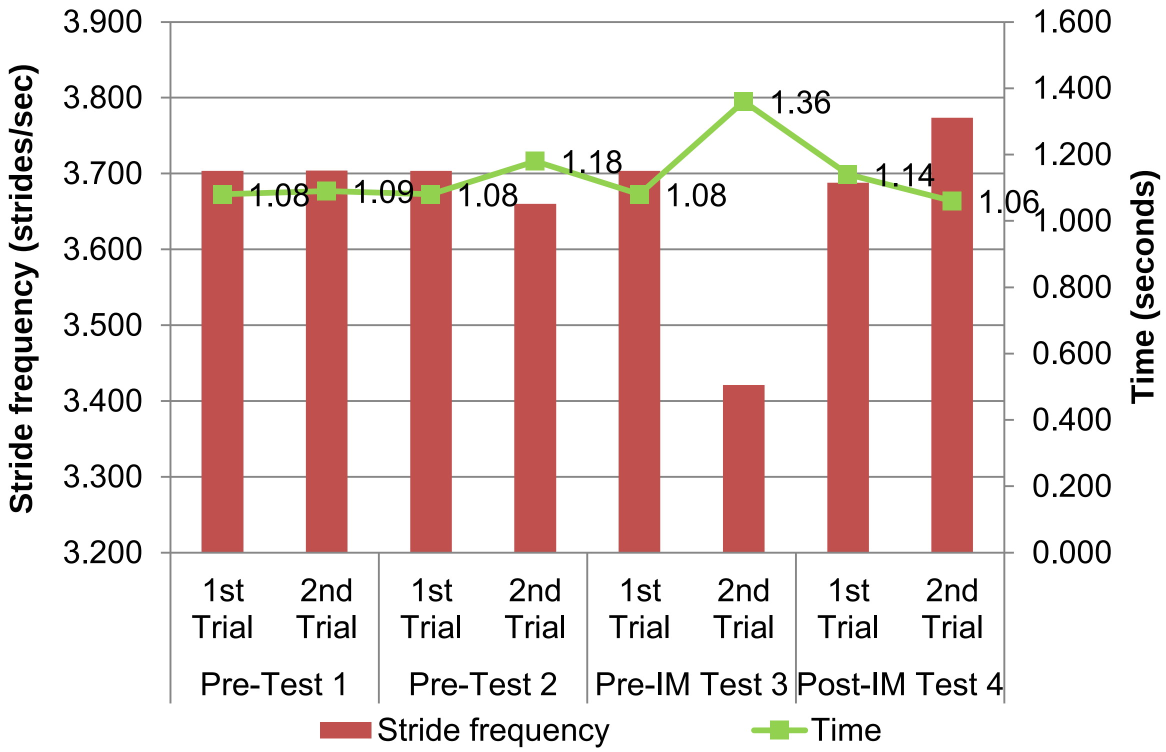


Figure 54. Stride frequency and the time taken during the maximal speed phase for Participant Three

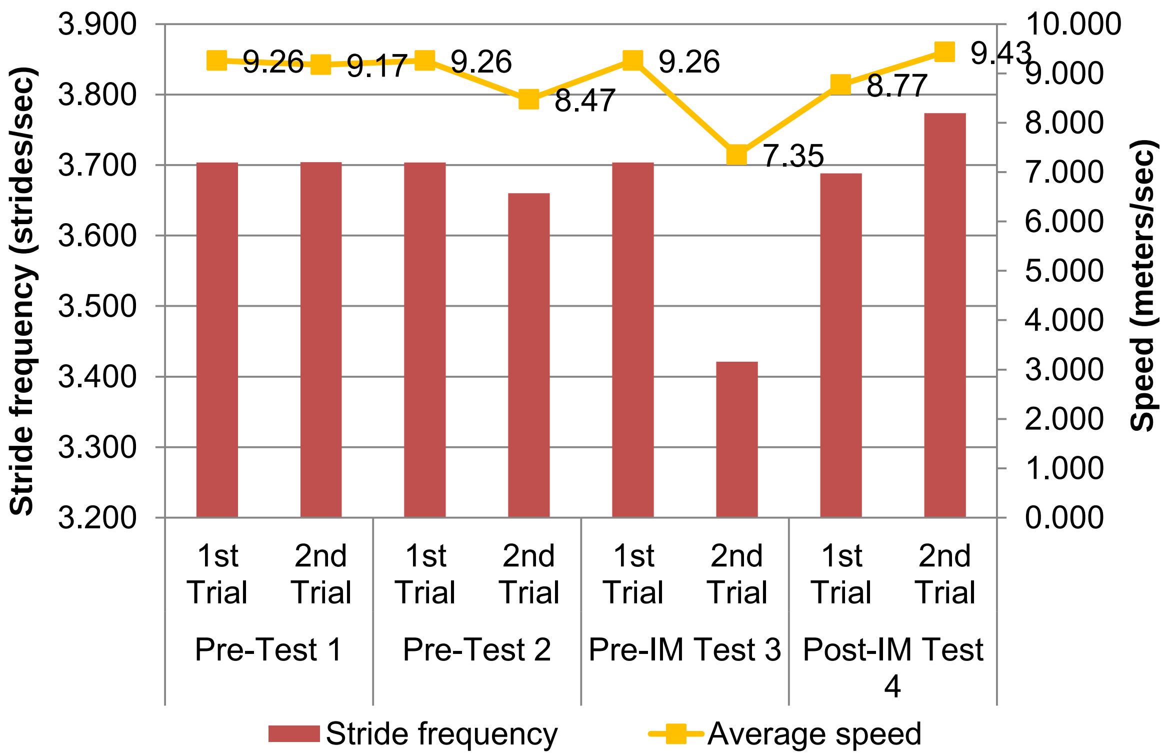


Figure 55. Stride frequency and the speed during the maximal speed phase for Participant Three

The correlation between stride frequency and stride length during the maximal acceleration phase was plotted (Figure 56) and found to have a very strong correlation (r = 0.96). The following can be noted:

- There is a constant average stride stride frequency that this athlete tends to stay at during this phase of the sprint.
- As this athlete increased his stride frequency while maintaining his long stride length, he performed at his best
- A balance between stride length and stride frequency appears key in the performance of this athlete.

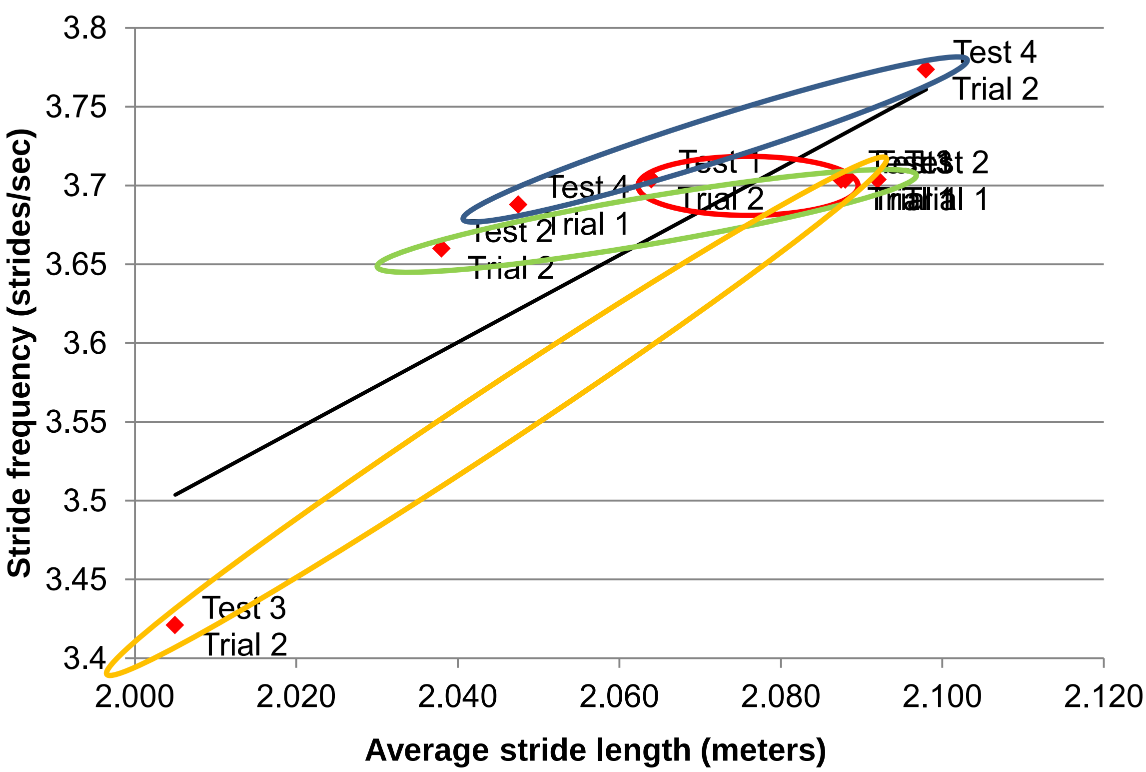


Figure 56. Correlation between stride frequency and average stride length during the maximal speed phase for Participant Three

Summary of the Variability Observed in the Sprinting Kinematics of Participant Three

Summary: Variability in the Set Position

The angles he created for both his ankles (front = 61.06 and rear = 180.54) along with both knees (front = 51.13 and rear = 28.77) and even rear hip (16.57) demonstrated the large variability over the course of the training year. With this athlete having cerebral palsy, these larger variability scores may be as a result of is disability, or otherwise that this athlete's coach adjusted his start setup and mechanics or he has because he has not been comfortable with the setup. This might have been so that he could feel more comfortable out of the blocks and to assist him feel more balanced and controlled into his running stride.

Summary: Variability during the Initial Acceleration Phase (0-10m)

This athlete's first stride out the blocks is quite stable in length throughout the eight trials, only fluctuating by 0.22m throughout the training year. His second stride was also stable in length fluctuating by only 0.17m throughout the training year. With this in mind it does not appear that the stride length is a key performance indicator for this phase of the sprint. However, from the third stride to the 10m mark, this athlete does seem to have a link between stride length and time as when stride length increases the time tends to drop, and vice versa. This pattern was mirrored when stride length was analysed in relation to speed, as stride length increased so did his speed. This tells us that the stride length is a performance indicator of this athlete during the first 10m of the sprint. There also appears to be a link for this athlete between the stride frequency and both time and speed. Stride frequency varies only between 3.22 and 3.57 strides per second.

The correlation between stride length and stride frequency during the initial acceleration phase is not strong ($r = 0.68$), it can be noted that stride frequency was higher at the end of the training year. For both of the trials on Test 1 (the beginning of the training year), a lower stride frequency can be noticed and a higher stride length, this was also when the slowest performances were recorded.

During the Test 2 and Test 3, moderate levels of stride frequency and stride length are achieved. All this information suggests that for this athlete's stride frequency appears to be the key performance indicator during the initial acceleration phase of the sprint.

Summary: Variability during the Maximal Speed Phase (30m-40m)

Stride length for this athlete was inconsistent over the training year. However, the athlete's time over these 10m did improve through the training year with the athlete running fastest in Test 4 and in Trial 2 (1.06s), yet these times were very fluctuating. This fastest trial coincides with the largest stride length at this stage (2.098m). The stride frequency of this athlete only fluctuated between 3.42 to 3.77 strides/sec (a difference of only 0.35 stride/sec) over the course of the training year, with both time and speed appearing to be closely linked to stride frequency (time decreased as stride frequency increased and vice versa; while speed increased as stride frequency increased and vice versa).

The correlation between stride frequency and stride length during the maximal acceleration phase was plotted and found to have a very strong correlation ($r = 0.96$). There was a constant average stride stride frequency that this athlete tends to stay at during this phase of the sprint. As this athlete increased his stride frequency while maintaining his long stride length, he performed at his best. A balance between stride length and stride frequency appears key in the performance of this athlete.

The Potential of Interactive Metronome Training™ to Influence the Sprinting Performance of Participant Three

Participant Three was actively involved in the Interactive Metronome Training™ programme during the period between Test Session 3 (Pre-IM training) and Test Session 4 (post-IM training). A comparison between his pre-test and post-test scored on IM precision timing is presented in Figure 57. It can be seen that there was an improvement in the millisecond accuracy following the intervention period on tasks for the hands only, feet only, left side of body, right side of body and bilateral. Table 12 presents the total summary for all task repetitions (3863) in the programme, and indicates that Participant Three achieved a 56.30% improvement in the precise timing of her movements after completing the intervention programme.

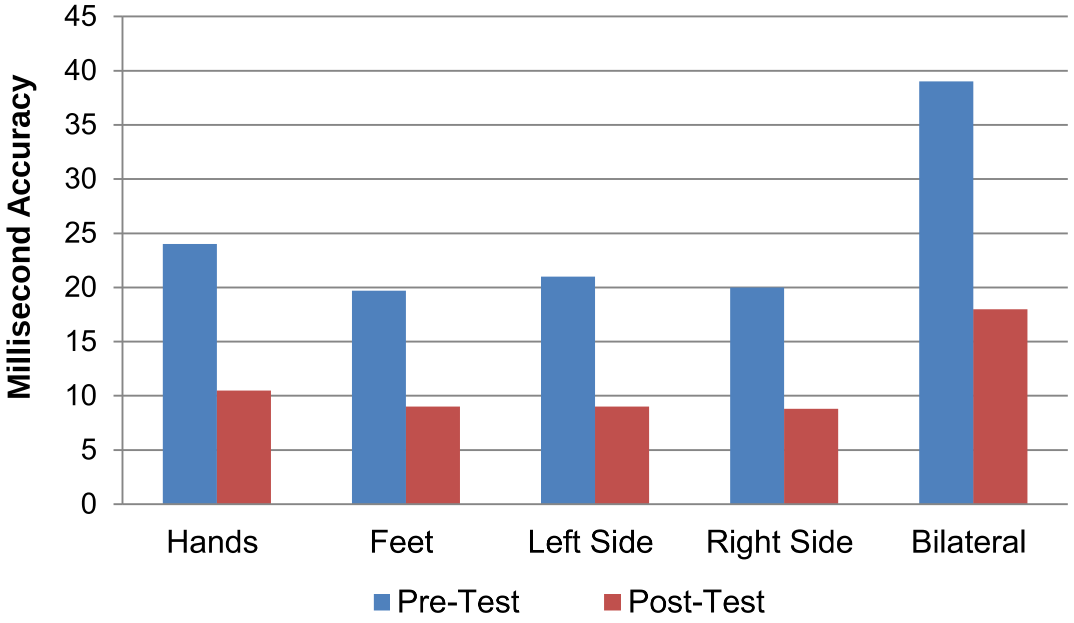


Figure 57. Millisecond accuracy improvements from the pre-test evaluation to the post-test evaluation in the IM training

Table 12

Pre- and post-test adjustment values and improvement following IM™ training for Participant Three.

Total Repetitions	Pre-Adjustment MS/Accuracy	Post-Adjustment MS/Accuracy	Improvement
3863	50.10/18.80%	21.90/46.00%	56.30%

Any signs of possible influence of IM™ training on the sprinting performance of Participant Three would have to be found in the differences in the sprint kinematics reported for Pre-IM Test 3 and Post-IM Test 4. The presentation of this data in the following figures is limited to the performance indicators of time, stride length and stride frequency in order to make this comparison clear.

The Potential Influence of IM™ training on the Sprinting Kinematics of Participant Three during the Initial Acceleration Phase (0-10m)

The following trends can be noted after the IM training for three of the key performance indicators during the initial acceleration phase:

- Time decreased very slightly - the participant ran faster (Figure 58).
- Stride length increased slightly and stabilized (Figure 59).
- Stride frequency increased (Figure 60).

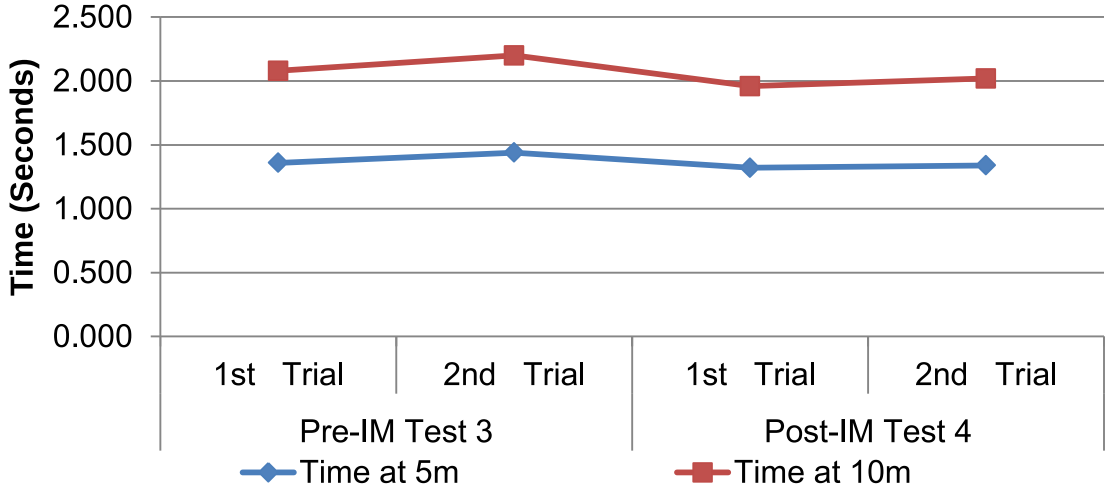


Figure 58. Time at 5m and 10m during the initial acceleration phase for Participant Three from pre- to post- IM™ training

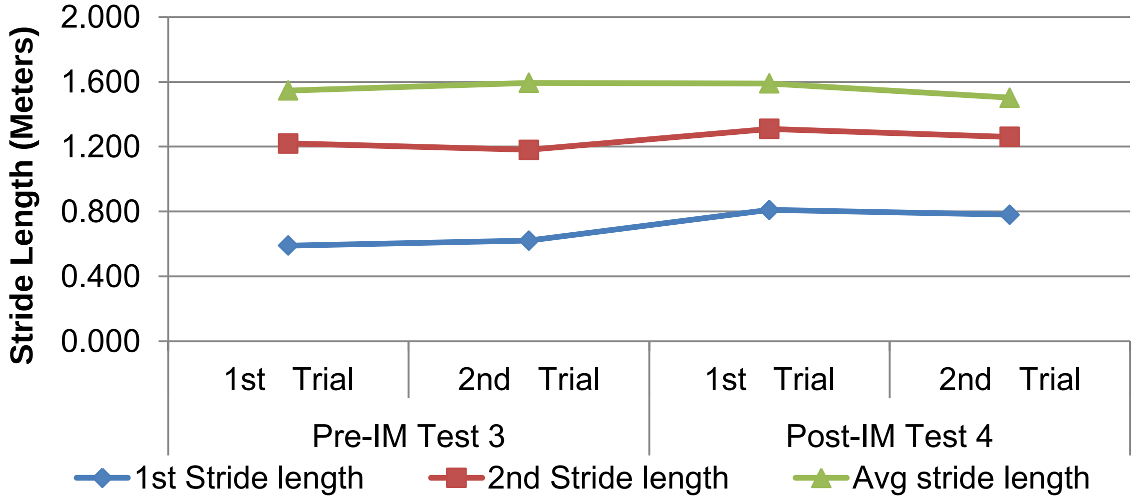


Figure 59. Stride length during the initial acceleration phase for Participant Three from pre- and post-IM™ training

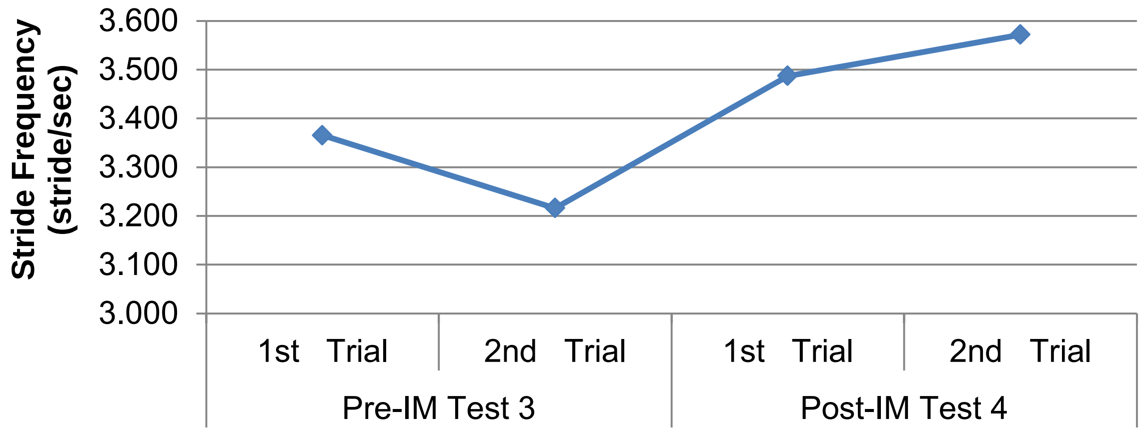


Figure 60. Stride frequency during the initial acceleration phase for Participant Three from pre- to post-IM™ training

If IM™ training had any influence on the initial acceleration phase, it would be on increasing stride frequency, which would have a positive impact on time.

The Potential Influence of IM™ Training on the Sprinting Kinematics of Participant Three during the Maximal Speed Phase (30m-40m)

The following trends can be noted after the IM training for three of the key performance indicators during the maximal acceleration phase:

- Time decreased slightly - the participant ran faster (Figure 61).
- Stride length increased (Figure 62).
- Stride frequency increased (Figure 63).

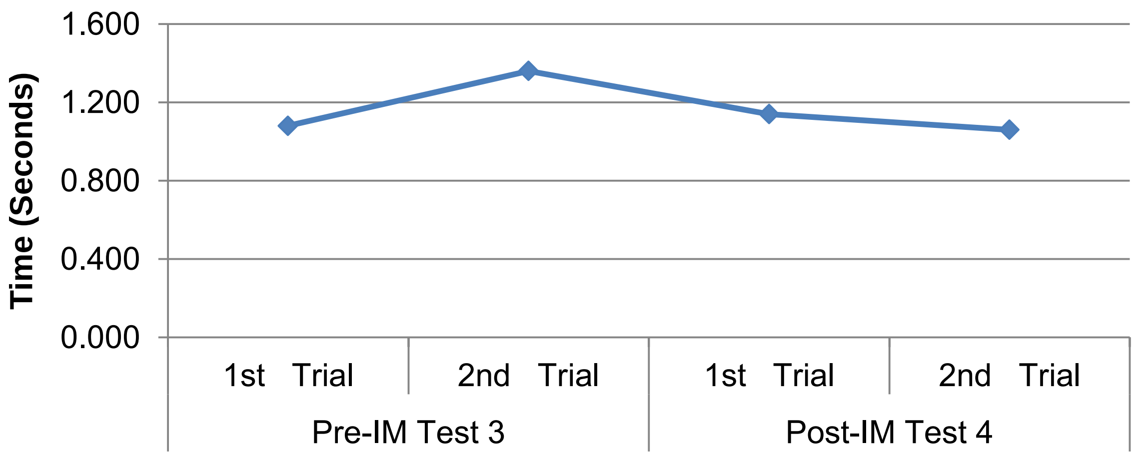


Figure 61. Time during the maximal speed phase for Participant Three from pre- to post-IM™ training

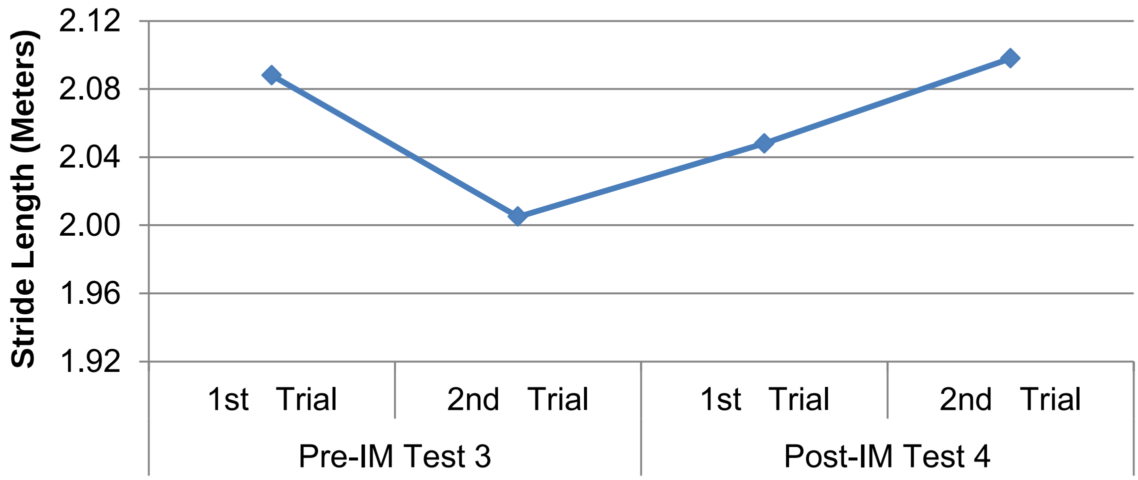


Figure 62. Stride length during the maximal speed phase for Participant Three from pre- to post-IM™ training

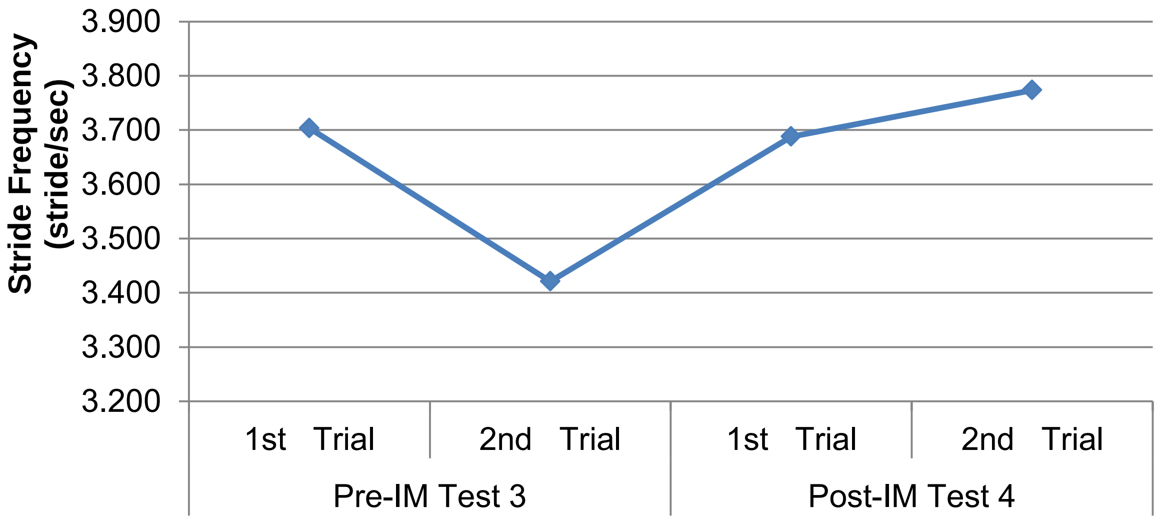


Figure 63. Stride frequency during the maximal speed phase for Participant Three from pre- to post-IM™ training

It appears that if IM™ training had any influence on the key performance indicators of the maximal acceleration phase, it would be on increasing stride length and increasing stride frequency, which had a positive impact on the sprinting time.

Subjective Information Provided by Participant Three

During the IM™ intervention period, observations were made and questions were asked by the researcher and Participant Three's responses were recorded in order to add context to understanding the potential the impact of IM™ training (Table 13).

Table 13

Subjective and observational log information for Participant Three

After 1 week of IM™ training	
Are you feeling more comfortable with the IM training?	Yes
Are you finding that you are becoming more rhythmic in your running?	No
Observations by Researcher	
His CP, which is not normally easily seen in his movements, became very evident through the exercise and he seemed to struggle to maintain his body control and balance during these exercises.	
After 3 weeks of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	Yes, minor
Observations by Researcher	
Started to noticeably become more comfortable in the exercises and able to control his balance far better, however the CP was still visible with the training.	
After completion of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	Yes
Do you feel that this training had a positive effect on your athletic abilities?	Yes
Do you feel that more/longer training on the IM device will be of any benefit?	No
Observations by Researcher	
His body control far better during the exercises and his overall movements far more exacting. The CP which had been evident throughout the training had become far less visible.	

Summary of the Potential Influence of IM Training on Sprint Kinematics of Participant Three

From the subjective information, it can be noted that the athlete did feel an improvement in the rhythm of her running and did feel that the IM™ training had a positive influence on his sprinting performance. However, he did not feel that more or longer IM™ training would be beneficial. The researcher perceived improvements to his ability to control his body better during the exercises, as well as an improvements in the precision with which Participant Three performed the various timing tasks.

In terms of sprint kinematics, however, there may have been a positive influence on stride frequency during the initial and maximal acceleration phase. This may indicate a positive area for future research because IM™ training has been associated with improvements in rhythm which could contribute to a faster stride rate and with improvements in coordination.

Case Study Four

Subject Four was born in 1984. He was diagnosed with cerebral palsy and this delayed his starting in athletics. He started to train in athletics in 2005 and started to compete at an elite level in 2006 in the T38 class. In 2011 he committed himself to serious training to sustain his participation at the elite level. His main event is the 400m, with his personal best being 52.27 which he set in 2006.

Unfortunately, this athlete missed the Pre-Test 1 testing session. The research questions are addressed in the following sections based on data from his performances on Pre-Test 2, Pre-IM Test 3 and Post-IM Test 4.

Variability of the Sprinting Kinematics of Participant Four

Data were collected during three testing sessions distributed throughout the training year. Reports of this data are presented to answer the three sub-questions related to variability in his sprinting kinematics.

Variability in the Set Position

The results of the biomechanical analysis of the set position for each of the three test sessions completed by this athlete are presented in Table 14. Variability is reported for each of the seven biomechanical features of the set position for Participant Four during each of the three test periods.

This athlete was new to high performance coaching and he received substantial amounts of corrective feedback from the coach to improve his sprint performance. The variance in the angles he created for his front ankle (17.6) and front knee (13.6) were large because he adjusted the positioning of the front block in an effort to have a more effective sprint start. This change also affected the angles created by his arms (25.3), leading to the higher variability there. These changes in the biomechanics of his set position were recommended by his coach based on her observations of his efficiency coming out of the blocks. His position at the time of Test 4, then, is probably his most optimal position.

Table 14

Results of the biomechanical features during the three tests for Participant Four.

	Pre-Test 2		**Pre-IM Test 3**		**Post-IM Test 4**		**Mean ± SD**	**V**
	1st Trial	**2nd Trial**	**1st Trial**	**2nd Trial**	**1st Trial**	**2nd Trial**		
Front Ankle	105.2	104.3	102.8	104.0	111.7	112.4	106.7 ± 4.2	17.6
Rear Ankle	100.1	99.7	99.2	100.0	103.7	103.9	101.1 ± 2.1	4.5
Front Knee	103.7	101.3	101.5	103.2	99.3	93.6	100.4 ± 3.7	13.6
Rear Knee	106.2	104.5	106.0	105.6	100.8	100.0	103.9 ± 2.8	7.6
Rear Hip	50.8	49.8	49.7	50.1	50.2	47.0	49.6 ± 1.3	1.8
Trunk	31.7	33.4	35.5	33.6	27.8	31.2	32.2 ± 2.6	6.9
Arms	123.4	121.4	126.3	123.4	117.1	112.5	120.7 ± 5.0	25.3

Variability during the Initial Acceleration Phase (0-10m)

The following figures (Figures 64 – 68) report the results of the analysis of the key performance indicators during the initial acceleration phase of the sprint for Participant Four over the three testing sessions. A complete table presenting the data collected on the kinematics of this initial acceleration phase is presented in Appendix C.

The relationship between the first two strides out of the blocks and their effect on time is shown in Figure 64. It is noticeable that the first stride out the blocks is consistent in length for the first four trials (Pre-Test 2 and Pre-IM Test 3) and then increases on Post-IM Test 4. However, the second stride is consistent throughout the six trials. The length of his first stride may have been related to the changes in his start position, indicating that the first stride may be the key to finding a fast and comfortable way to leave the blocks.

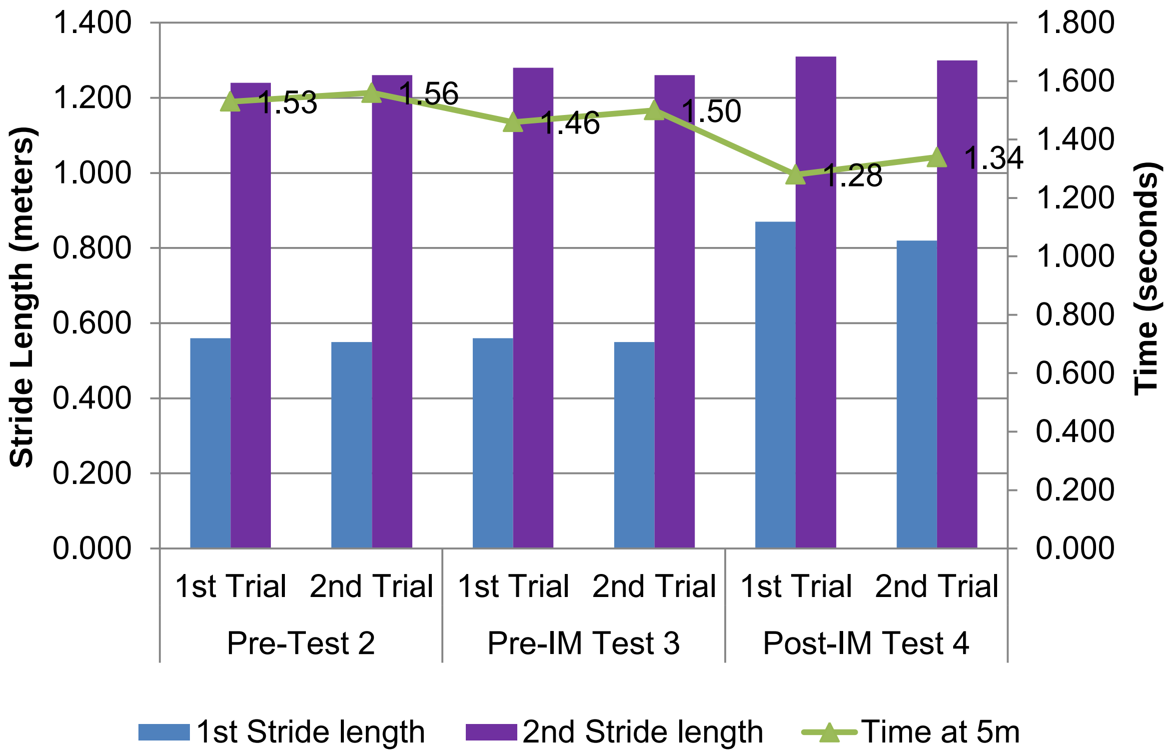


Figure 64. First two stride lengths and time taken during the initial acceleration phase for Participant Four

The role of stride length for this athlete was less evident when the kinematics for the third stride through the 10m mark are tracked (Figure 65). It can be seen that his average stride length varied between 1.50m and 1.62m. Although his fastest time (2s) was achieved with his longest average stride length (1.62m), his longer stride lengths were not always related to faster times. In fact, during Pre-Test 2 he lengthened his stride on Trial 2 and achieved a slightly slower time.

When stride length was analysed in relation to speed (Figure 66), a similar pattern less result was seen. This tells us that for the performance of this athlete, stride length alone over the first 10m of the sprint is not the critical performance indicator.

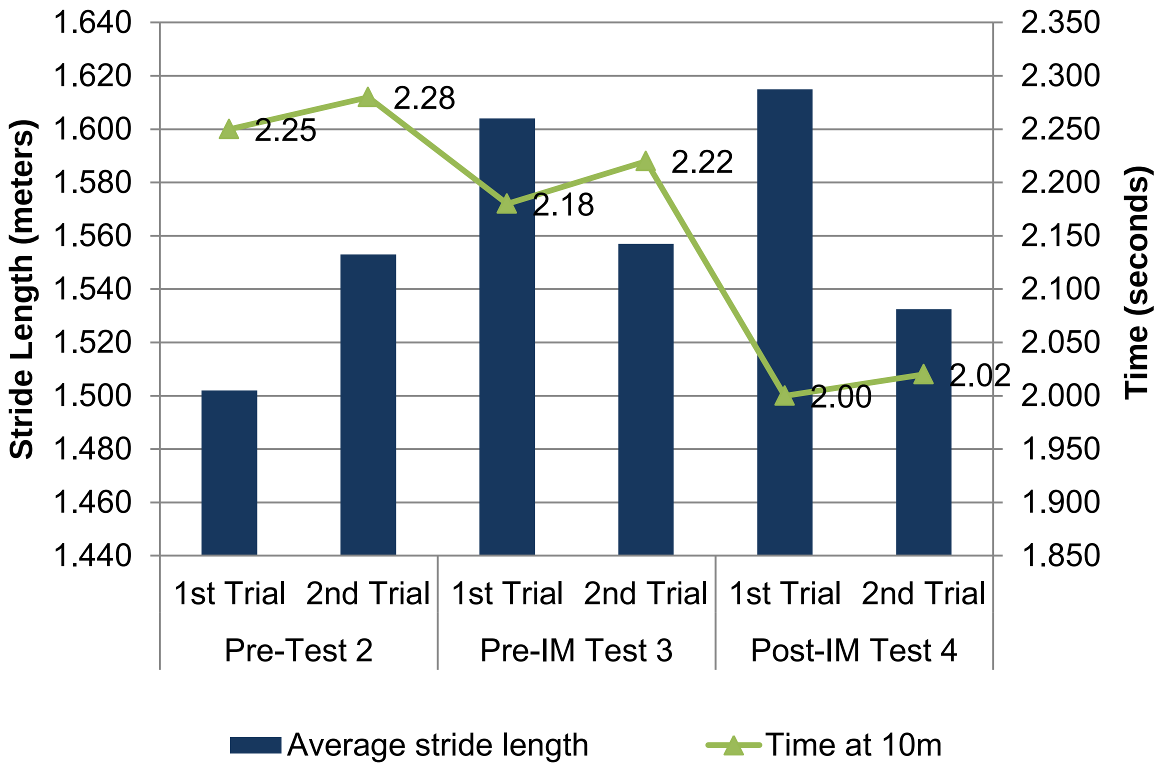


Figure 65. Average stride length (3rd stride to 10m) and time taken during the initial acceleration phase for Participant Four

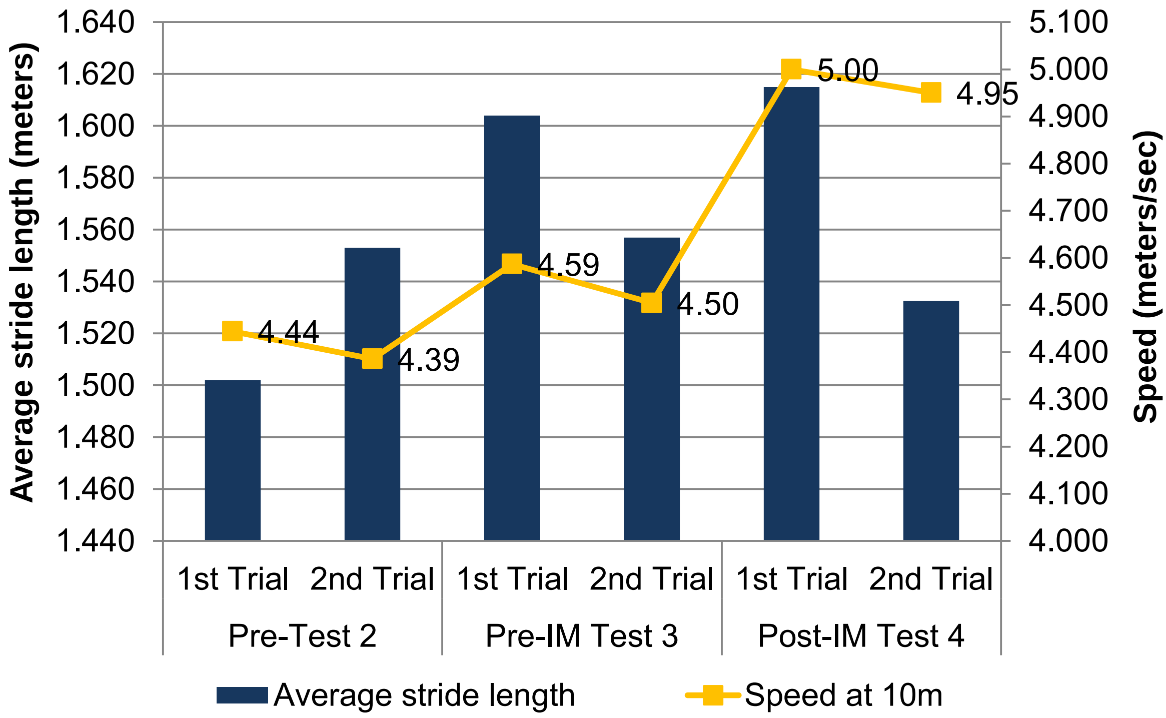


Figure 66. Average stride length (3rd stride to 10m) and speed during the initial acceleration phase for Participant Four

In *Figures 67* and 68, variability in stride frequency is shown in relation to time and to speed for this athlete.

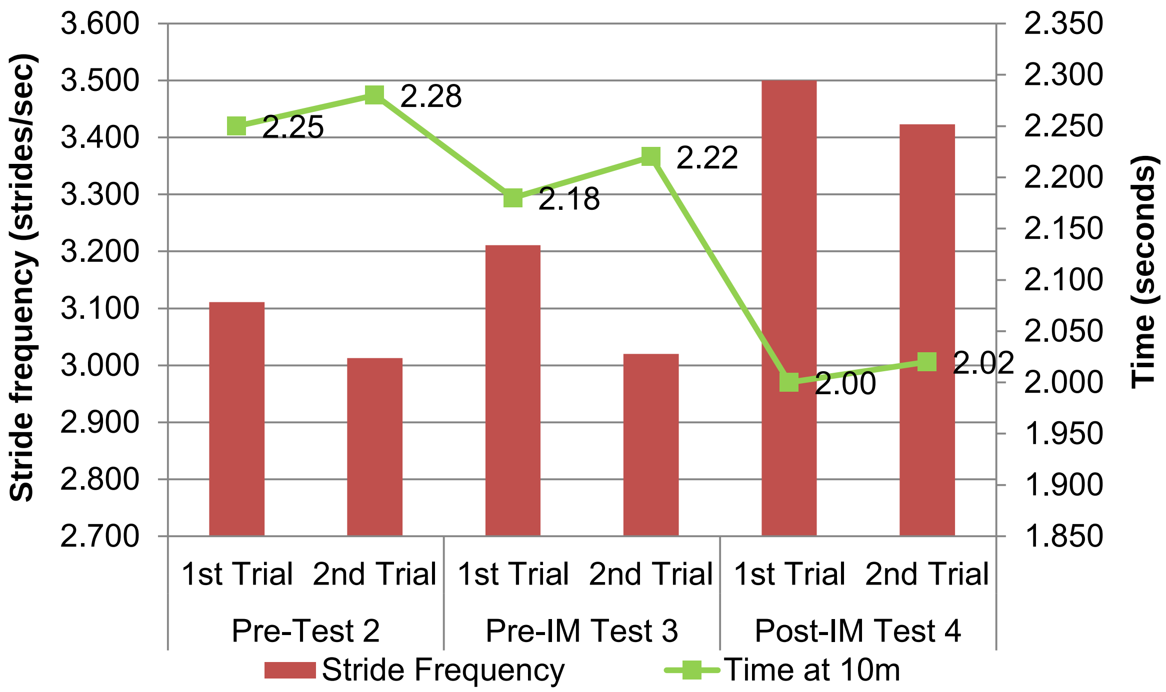


Figure 67. Stride frequency and time taken during the initial acceleration phase for Participant Four

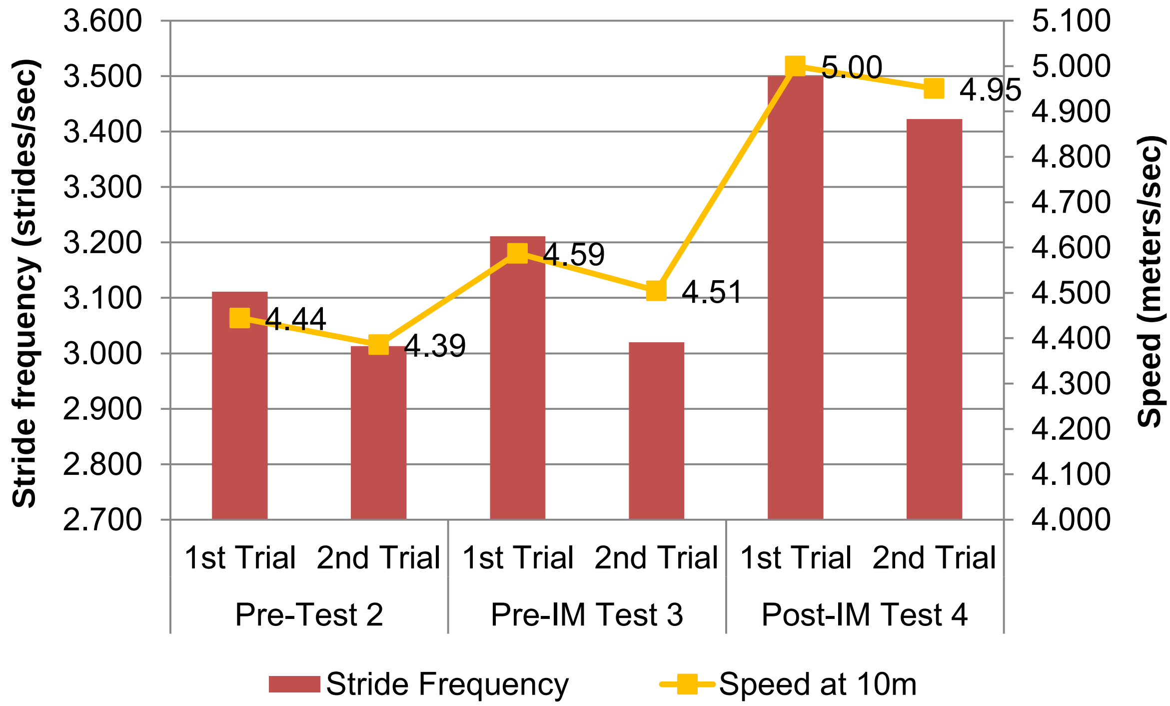


Figure 68. Stride frequency and speed during the initial acceleration phase for Participant Four

There appears to be a clear link between the stride frequency and time and in speed when the third stride to 10m is analysed. Stride frequency varies between 3.01 and 3.50 strides per second. When stride frequency is increased, time decreases and speed increases. This would point to stride frequency as the critical focus for this athlete from 0-10m.

The correlation between stride length and stride frequency during the initial acceleration phase is presented in Figure 69. Although the correlation calculation over all three test sessions is not strong (r = 0.40), it can be noted that for both of the trials on Test 2 (circled in green) and Test 3 (circled in yellow), a lower stride frequency can be noticed. On Test 4 (the end training year, circled in blue) the highest rates of stride frequency were achieved and the fastest times were recorded. Although finding the optimal combination of stride frequency with stride length remains his goal during the initial acceleration phase of the sprint to optimize performance, it appears that stride frequency is the key to top performances.

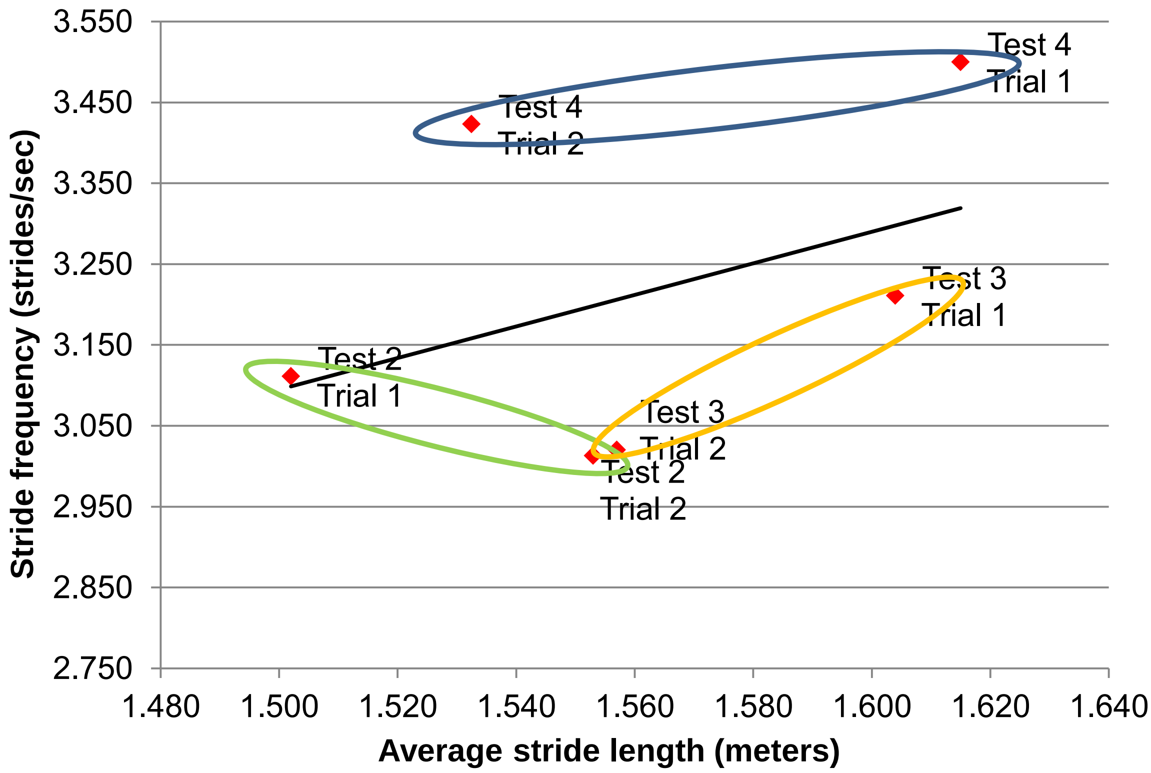


Figure 69. Correlation between stride frequency and stride length during the initial acceleration phase for Participant Four

Variability during the Maximal Running Velocity Phase (30m-40m)

The following figures (Figures 70 – 73) report the results of the analysis of the key performance indicators during the maximal running velocity phase of the sprint for Participant Four over the three testing sessions. A complete table presenting the data collected on the kinematics of this phase is presented in Appendix C.

Stride length from the 30m to the 40m mark was inconsistent over the training year (Figure 70). The athlete's time over these 10m was also quite inconsistent. The athlete ran his fastest times in Test 3 Trial 1 and in Test 4 Trial 1 (1.1s) while his stride length varied between these trials (2.02m and 1.99m respectively). When he lengthened his stride length on Test 3 Trial 2 to 2.07m, his time became marginally slower.

The effect of stride length on speed is reflected in Figure 71 which documents this same inconsistent pattern of relationships.

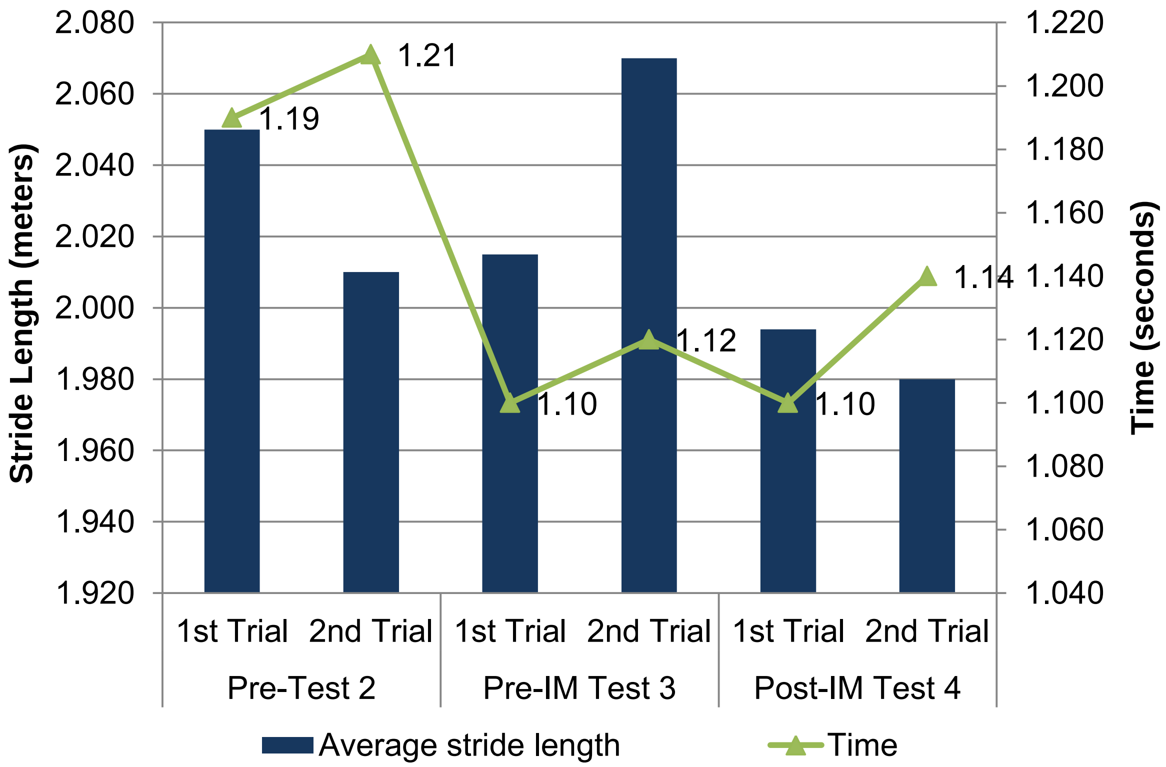


Figure 70. Average stride length and time taken during the maximal running velocity phase for Participant Four

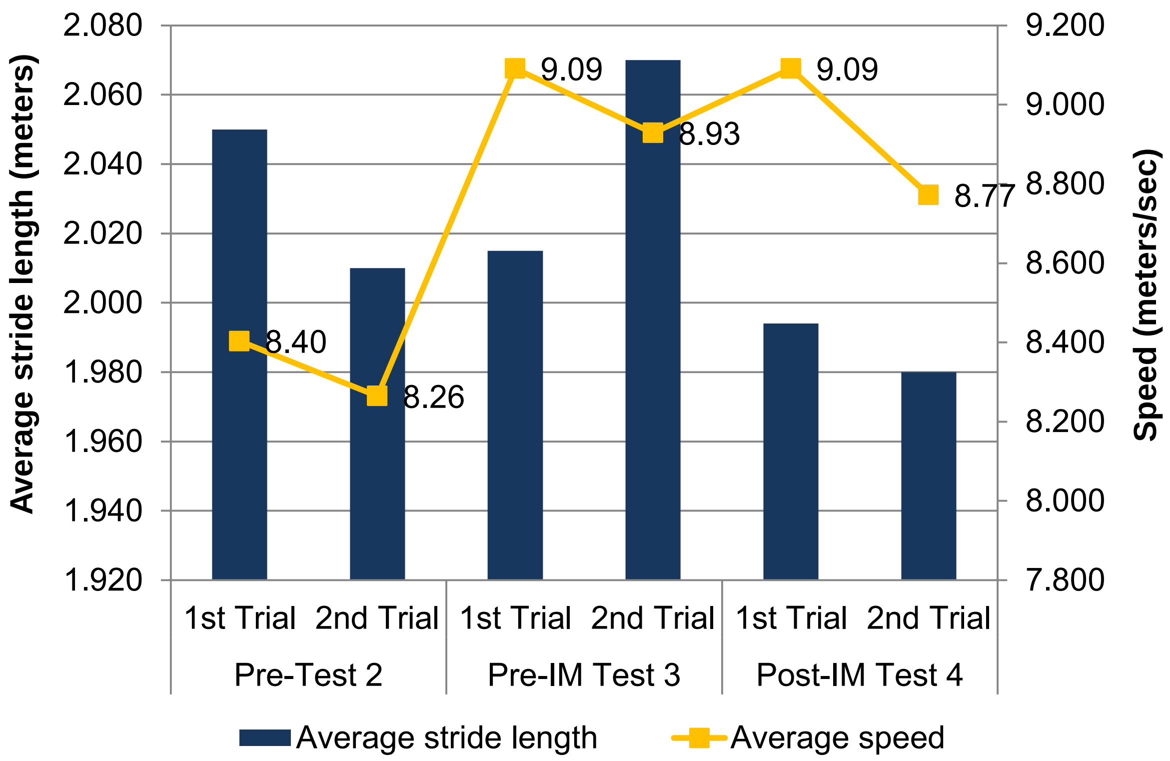


Figure 71. Average stride length and the speed during the maximal running velocity phase for Participant Four

When stride frequency from the 30m to the 40m mark is compared to time (Figure 72), the slowest times (Test 2 Trials 1 and 2) are associated with the lowest stride frequencies. As stride frequencies increases, time decreases with the fastest times (1.10s) associated with the higher stride frequencies (4.55 strides/sec on Trial 1 for both Test 3 and Test 4).

When examining the relationship between stride frequency and speed (Figure 73), this athlete fluctuated between 4.20 to 4.55 strides/sec (a difference of 0.35 stride/sec) over the course of the training year. It does appear that increases in speed are positively linked with increases in stride frequency increased and vice versa.

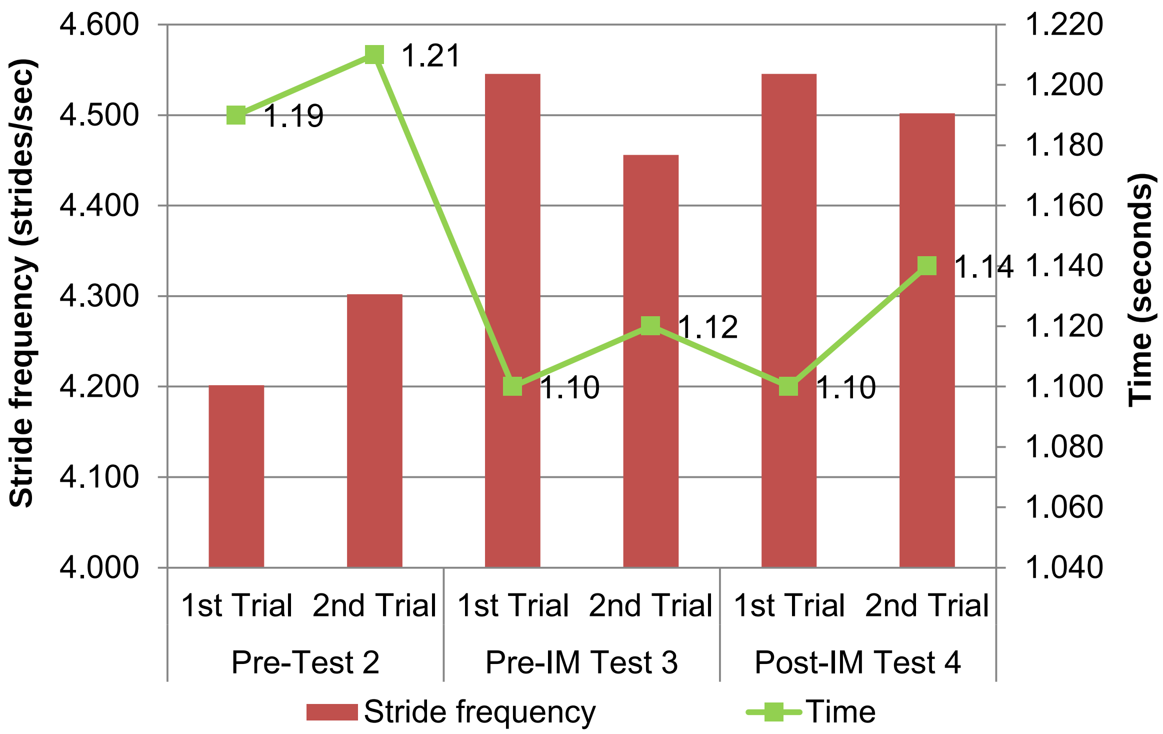


Figure 72. Stride frequency and the time taken during the maximal running velocity phase for Participant Four

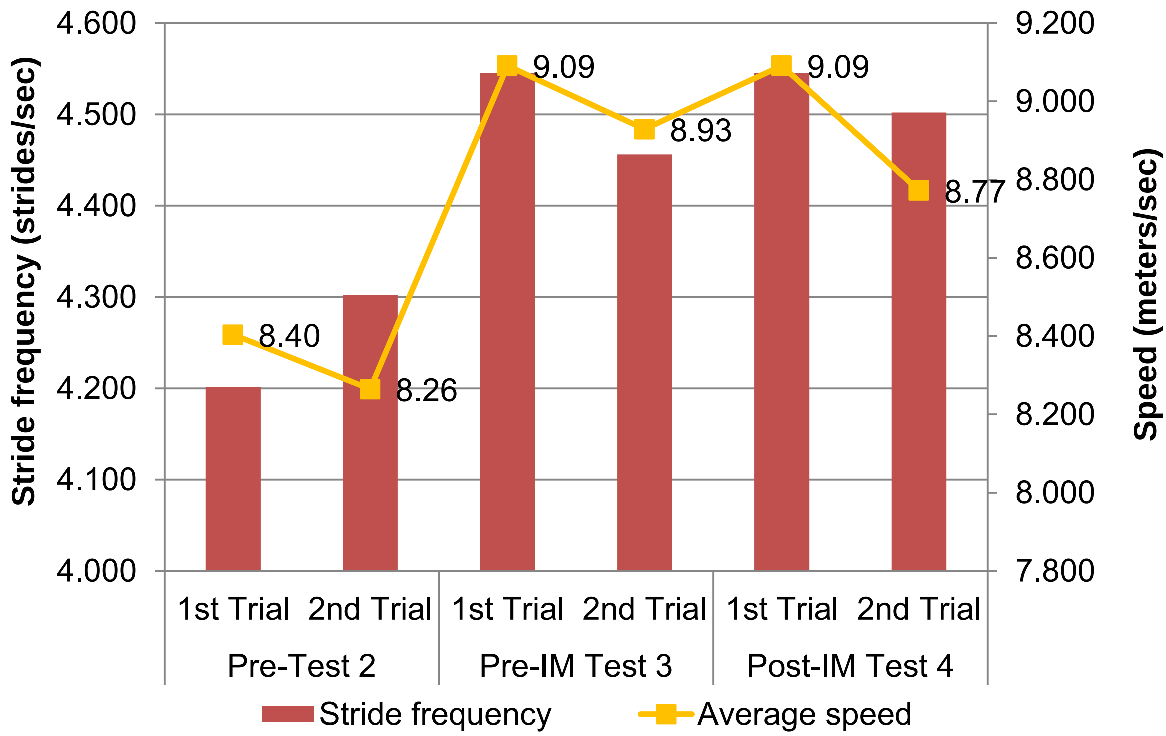


Figure 73. Stride frequency and the speed during the maximal running velocity phase for Participant Four

The correlation between stride frequency and stride length during the maximal running velocity phase was plotted (Figure 74) and found to have a fairly weak correlation (r = 0.44). The following can be noted:

- The average stride frequency length from Test 2 (circled green) to Test 4 (circled blue) increased while the stride length was variable.
- The progressive increase in stride frequency (from 4.20 to 4.55 strides/sec) supports the focus on stride frequency as the key to this athletes speed. The optimal relationship between stride length and stride frequency appears to be found with a shorter stride length and higher stride frequency.

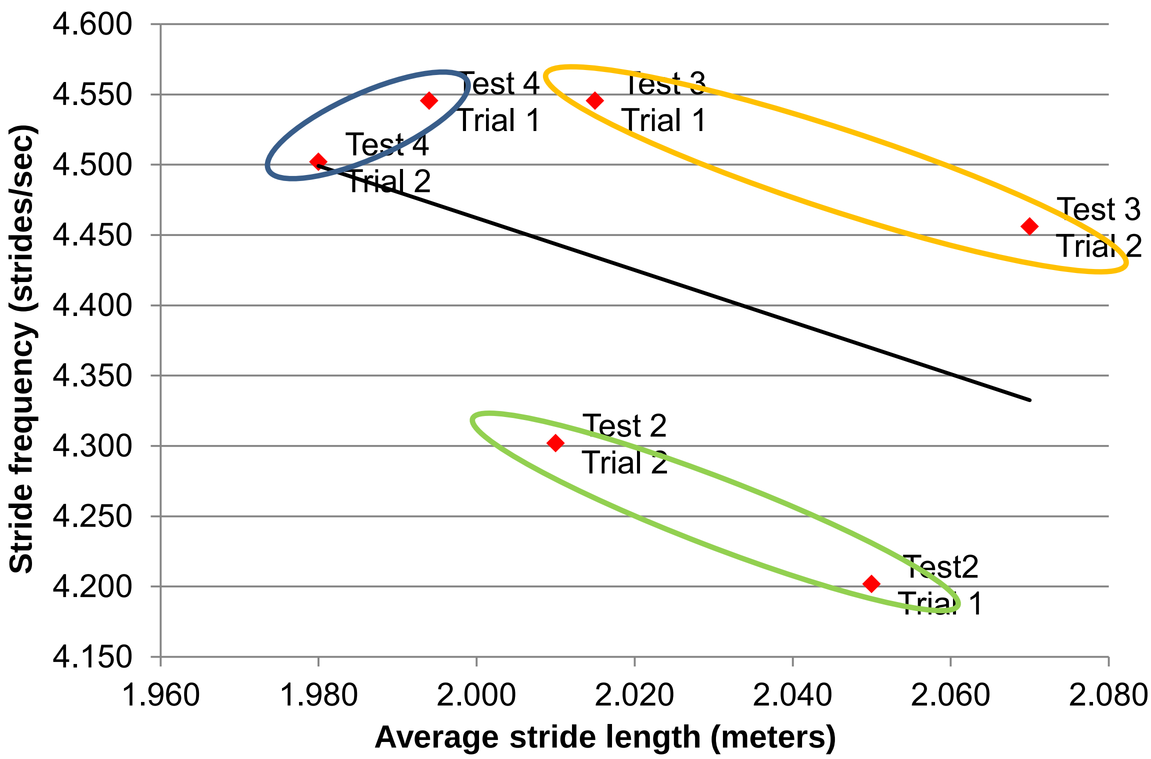


Figure 74. Correlation between stride frequency and average stride length during the maximal running velocity phase for Participant Four

Summary of the Variability Observed in the Sprinting Kinematics of Participant Four

Summary: Variability in the Set Position

This athlete was the least experienced and newest to the training group. He now had sustained contact with a professional coach and therefore was receiving much corrective feedback to improve his sprint performance. The variability in the angles he created for his front ankle (17.6) and front knee (13.6) were large because he adjusted the positioning of the front block in an effort to have a more effective sprint start. This change also affected the angles created by his arms (25.3) and lead to the higher variability here. All these changes were corrective and advantageous to his sprint performance.

Summary: Variability during the Initial Acceleration Phase (0-10m)

For this athlete the first strides out the blocks were consistent in length for the Test 2 and Test 3 (4 trials) and then increased on Test 4. However, the second stride was consistent throughout the six trials. The increase in first stride length also coincided with the decrease in time possibly indicating that this may be the key to performance for this phase of the sprint.

There appears to be a clear link between the stride frequency and time and speed when the third stride to 10m is analysed. Stride frequency varied between 3.01 and 3.50 strides per second. This would point to stride frequency as the critical focus for this athlete from 0-10m.

The correlation between stride length and stride frequency during the initial acceleration phase was found not to be strong (r = 0.40). However, on Test 4 (the end training year) the highest rates of stride frequency and compatible stride lengths were found and the fastest times and speeds recorded. This suggests that the athlete found an optimal combination of stride frequency with stride length.

Summary: Variability during the Maximal Running Velocity Phase (30m-40m)

Stride length from the 30m to the 40m mark was inconsistent over the training year. It does appear that time and speed are linked to stride frequency for this athlete, with time decreasing as stride frequency increased and vice versa, and speed increasing as stride frequency increased and vice versa.

The correlation between stride frequency and stride length during the maximal running velocity phase was plotted and found to have a fairly weak correlation (r = 0.44). The average stride frequency from Test 2 to Test 4 increased while the stride length was variable. The progressive increase in stride frequency (from 4.20 to 4.55 strides/sec) supports the focus on stride frequency as the key to this athletes speed.

The Potential of Interactive Metronome Training™ to Influence the Sprinting Performance of Participant Four

Participant Four was actively involved in the Interactive Metronome Training™ programme during the period between Test Session 3 (Pre-IM training) and Test Session 4 (Post-IM training). A comparison between his pre-test and post-test scored on IM precision timing is presented in Figure 75. It can be seen that there was an improvement in the millisecond accuracy following the intervention period on tasks for the hands only, feet only, left side of body, right side of body and bilateral. Table 15 presents the total summary for all task repetitions (3838) in the programme, and indicates that Participant Four achieved an 88.8% improvement in the precise timing of his movements after completing the intervention programme.

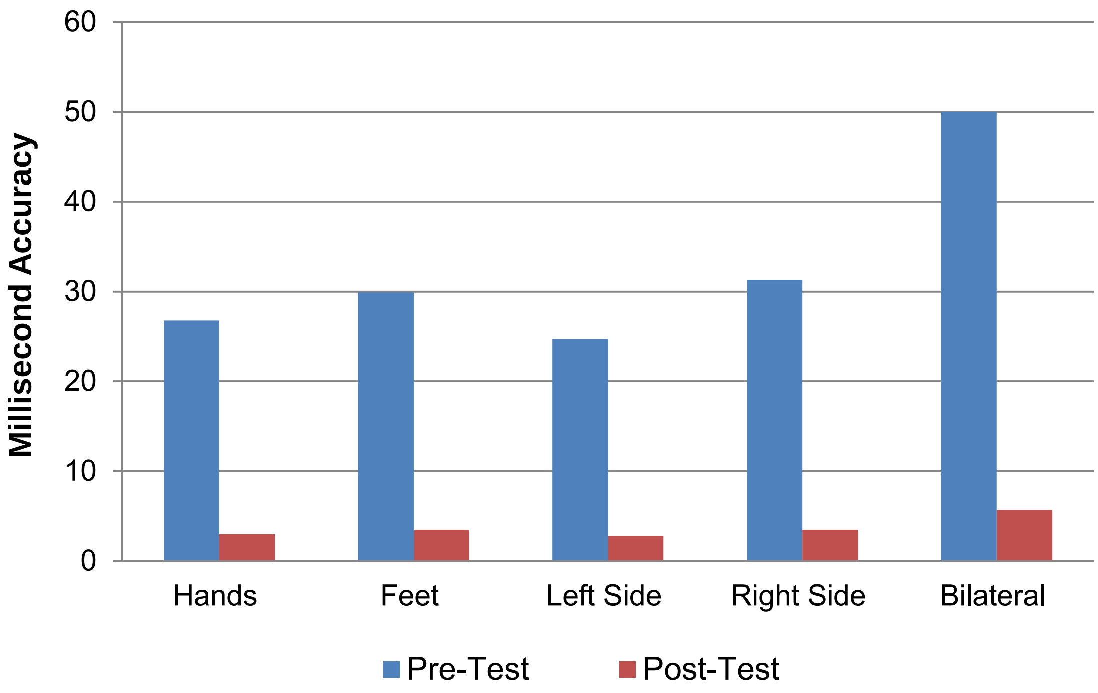


Figure 75. Millisecond accuracy improvements from the pre-test evaluation to the post-test evaluation in the IM training

Table 15

Pre- and post-test adjustment values and improvement following IM™ training for Participant Four.

Total Repetitions	Pre-Test Adjusted Value	Post-Test Adjusted Value	Pre- to Post-Test Improvement
3838	253.10/5.70%	28.30/38%	88.80%

Any signs of possible influence of IM™ training on the sprinting performance of Participant Four would have to be found in the differences in the sprint kinematics reported for Pre-IM Test 3 and Post-IM Test 4. The presentation of this data in the following figures is limited to the performance indicators of time, stride length and stride frequency in order to make this comparison clear.

The Potential Influence of IM™ training on the Sprinting Kinematics of Participant Four during the Initial Acceleration Phase (0-10m)

The following trends can be noted after the IM training for three of the key performance indicators during the initial acceleration phase:

- Time decreased - the participant ran faster (Figure 76).
- Stride length – for first stride increased, second stride slight increase and average stride (3rd to 10m) stayed the same (Figure 77).
- Stride frequency increased (Figure 78).

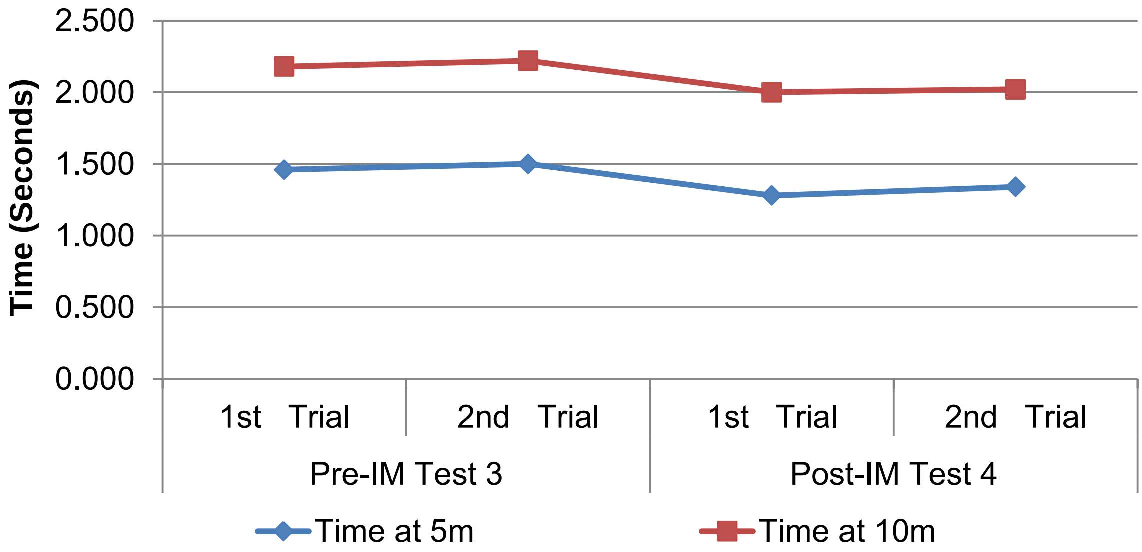


Figure 76. Time at 5m and 10m during the initial acceleration phase for Participant Four from pre- to post- IM™ training

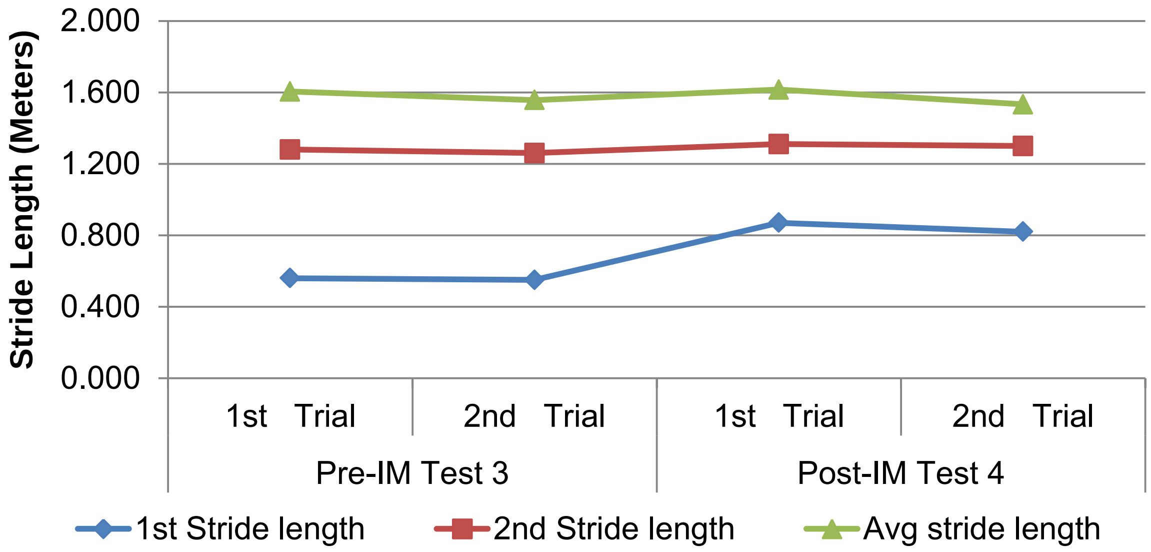


Figure 77. Stride length during the initial acceleration phase for Participant Four from pre- and post-IM™ training

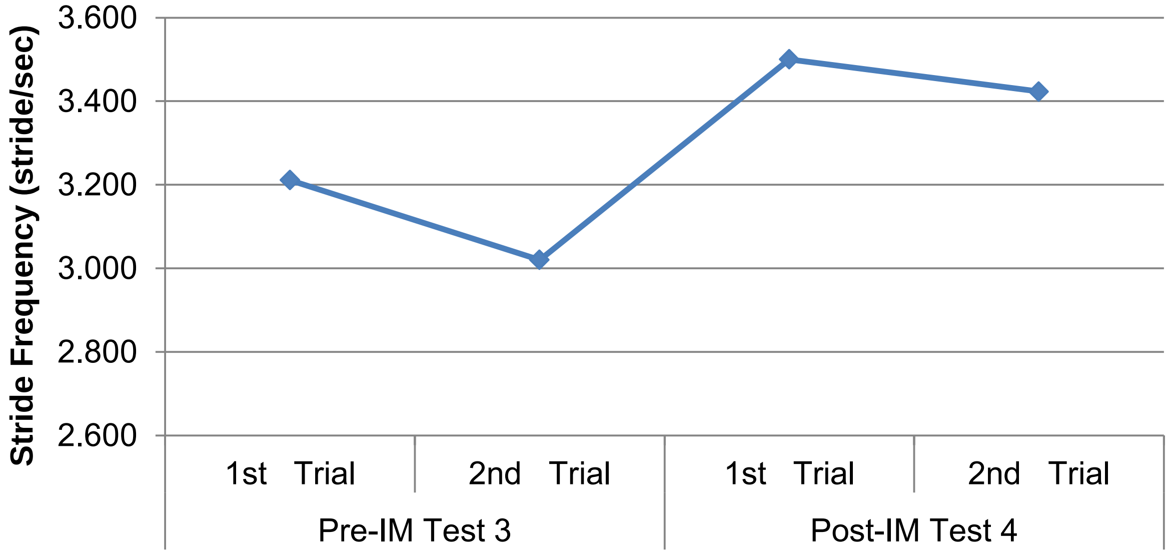


Figure 78. Stride frequency during the initial acceleration phase for Participant Four from pre- to post-IM™ training

If IM™ training had any influence on the initial acceleration phase, it would be on increasing the first stride out of the blocks, and/or increasing the stride frequency, both of which would have a positive impact on time.

The Potential Influence of IM™ Training on the Sprinting Kinematics of Participant Four during the Maximal Running Velocity Phase (30m-40m)

The following trends can be noted after the IM training for three of the key performance indicators during the maximal running velocity phase:

- Time decreased - the participant ran faster (Figure 79).
- Stride length decreased (Figure 80).
- Stride frequency increased (Figure 81).

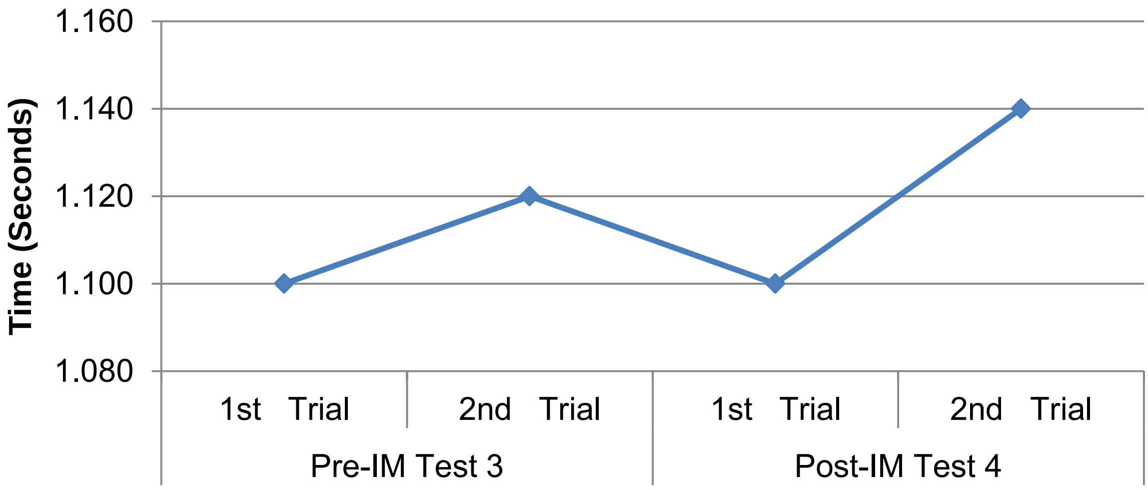


Figure 79. Time during the maximal running velocity phase for Participant Four from pre- to post-IM™ training

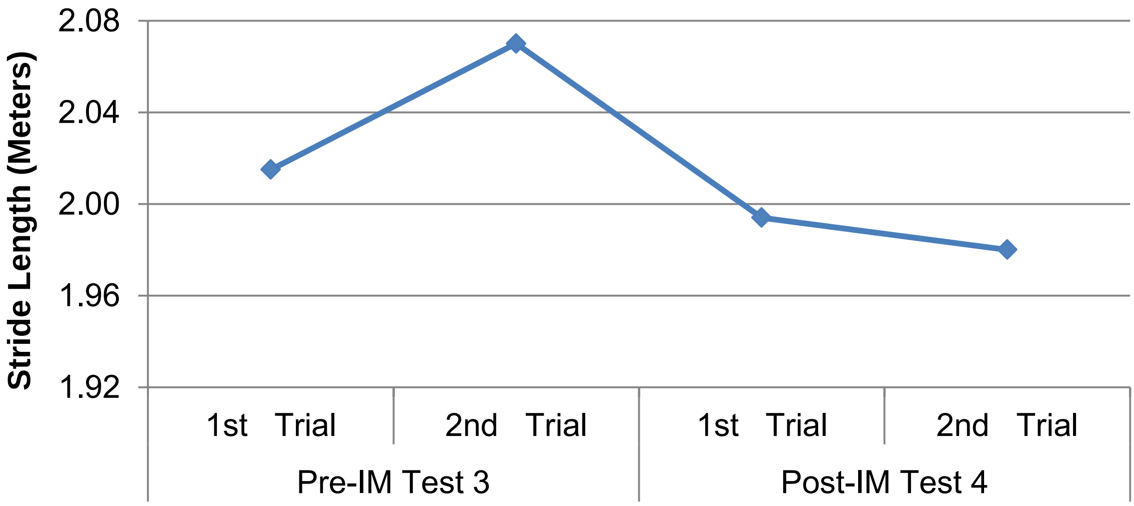


Figure 80. Stride length during the maximal speed phase for Participant Four from pre- to post-IM™ training

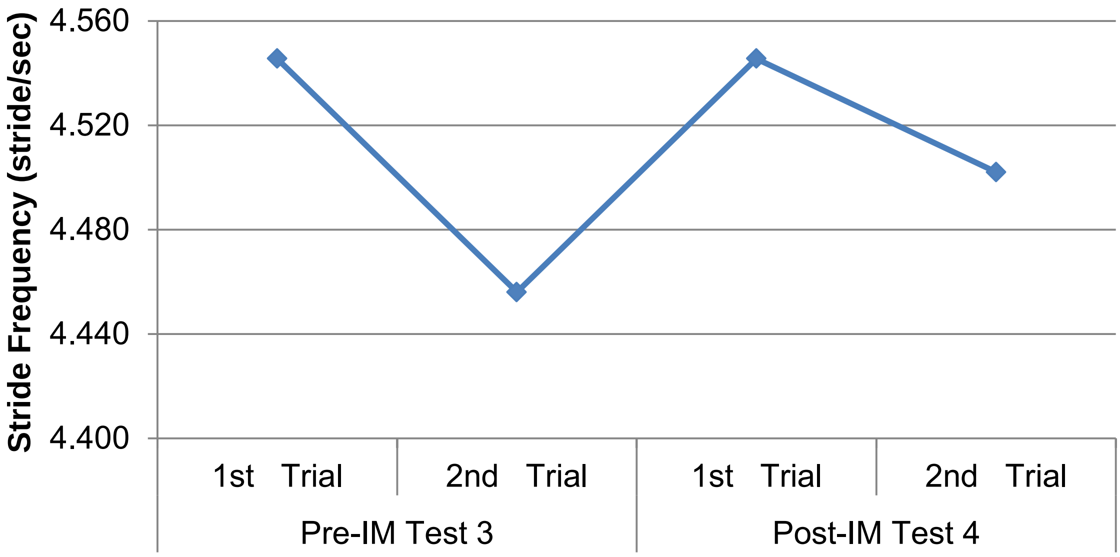


Figure 81. Stride frequency during the maximal speed phase for Participant Four from pre- to post-IM™ training

It appears that if IM™ training had any influence on the key performance indicators of the maximal running velocity phase, it would be on decreasing stride length and try to find the optimal balance between stride length and frequency, which had a positive impact on the sprinting time.

Subjective Information Provided by Participant Four

During the IM™ intervention period, observations were made and questions were asked by the researcher and Participant Four's responses were recorded in order to add context to understanding the potential the impact of IM™ training (Table 16).

Table 16

Subjective and observational log information for Participant Four

After 1 week of IM™ training	
Are you feeling more comfortable with the IM training?	Yes
Are you finding that you are becoming more rhythmic in your running?	Yes
Observations by Researcher	
Very insecure in his movements and body control. Demonstrated poor balance and ability to coordinate his various body parts. All this seemed to cause him much distress and he appeared to almost over focus on the tasks at hand, with the CP becoming very evident.	
After 3 weeks of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	Yes
Observations by Researcher	
He really seemed to start to enjoy the training and did not become nearly as anxious when he made a mistake. His balance, coordination and body movements far more controlled and exacting. The CP was no longer nearly as visible.	
After completion of IM™ training	
Are you finding that you are becoming more rhythmic in your running?	Yes
Do you feel that this training had a positive effect on your athletic abilities?	Yes
Do you feel that more/longer training on the IM device will be of any benefit?	Yes
Observations by Researcher	
Became the most accurate and coordinated of all the athletes. Showed a real enthusiasm for the training and he out of all the athletes said that he felt more coordinated and rhythmical in his sprinting following the training and that he really benefitted from the training.	

Summary of the Potential Influence of IM Training on Sprint Kinematics of Participant Four

From the subjective information, it can be noted that the athlete did feel an improvement in the rhythm of her running and did feel that the IM™ training had a positive influence on his sprinting performance. Interestingly, he was the only participant to feel that more or longer IM™ training would be beneficial. This could be due to him being less experienced than the other participants.

In terms of sprint kinematics, there may have been a positive influence on stride frequency during the initial and maximal running velocity phase. This may indicate a positive area for future research because IM™ training has been associated with improvements in rhythm and balance, which could contribute to a faster stride rate and with improvements in bilateral coordination when sprinting.

The researcher observed improvements in his ability to control his balance, coordination and body movements, making his actions more precise and accurate. Overall, Participant Four's body movements became more rhythmical and he performed the various timing tasks with much more ease and confidence.

Chapter Five

Discussion, Conclusions and Recommendations

A case study approach was taken in this research intended to develop coaching knowledge about the training of sprinters with disabilities. The specific focus was on learning more about variability in the initial acceleration phase and the maximum acceleration phase as performed by Paralympic sprinters from three different disability groups. Two research questions were formulated and then applied to these two phases of the sprint (Figure 82). Sprint performances were recorded during four test sessions, conducted in December, May, June and August in one training year.

- The results from all four sessions were used to track variability in the set position and in the kinematic variables of stride length and stride frequency throughout the training year.
- The results of Sessions Three and Four were compared in terms of identifying selected kinematic changes that might have been influenced by the athletes' participation in a rhythm training programme, delivered as a training intervention between those two test sessions.

RO 1a
The variability observed in the the biomechanical features of the set position

Acceleration 0-10m

Maximum Running Velocity 30-40m

The variability observed in:		
RQ 1b: Stride length and stride frequency during initial acceleration		**RQ 1c**: Stride length and stride frequency during maximal running velocity
RQ 2:The effects of a rhythmic training programme on:		
RQ 2a: Sprint performance during initial acceleration		**RQ 2b:** Sprint performance during the maximum running velocity

Figure 82. The focus of the two research questions on sprint performance

Discussion

The following discussion is presented to address each of the research questions.

Research Question One

What variability can be observed in the sprinting kinematics of Paralympic sprinters?

A summary for the findings regarding variability are presented in Table 17.

Table 17

Summary of the variability results for all participants.

Participant & Class	Biomechanics of the Set Position	Initial Acceleration		Max Velocity
		Steps 1 & 2	3rd to 10m	30m-40m
1 (T43)	Most variability in rear knee and front hip in search of optimal compression with prosthesis as he leaves the blocks	Key to a fast time is the length of his second stride (prosthetic leg)	Stride length is the key focus for coaches	Stride length is the key focus for coaches
2 (T13)	Most variability in arms showing she is in search of a more balanced, rhythmic exit from the blocks	A short first stride and longer second is key to sprint performance	Stride frequency is the key focus for coaches	Stride frequency is the key focus for coaches
3 (T37)	Variability in both ankles, both knees and rear hip in search of more economical exit from blocks	Consistency in stride lengths key to performance	Stride length and frequency are the key focus areas for coaches	Stride frequency is the key focus for coaches
4 (T38)	High level of variability among sessions on all features while searching for his optimal set position	A longer first stride appears key to improved performance over the year	Stride frequency is the key focus for coaches	Stride frequency is the key focus for coaches

Research Question 1a

What variability can be observed in the biomechanical features of the set position of the sprint start of a Paralympic athlete over the course of a training year?

For sprinters, variability in the set position is expected in response to performance in a variety of environmental circumstances (Bradshaw *et.al.* 2007). This means that coaches should expect some variability in their athlete's biomechanics, even once an optimal set position has been identified. For some coaches, the may require them to redefine their ideas about consistency in performance. It does not mean a lack of variability in technique, but rather finding the motor control strategy that will support consistent performance under changing environmental circumstances.

This focus on finding a flexible motor control strategy is consistent with research about sprinting that has established that for an optimal sprint start, maximal effort and force is required to drive the body from a stationary position in the blocks, out and into an optimal position for sprinting (Čoh *et.al.* 2009; Bradshaw, Maulder & Keogh, 2007; Harland & Steele, 1997). In his explanation of movement variability, Lee (2011) noted that Schmidt's Law states that variability will be proportional to the force required to initiate the movement. Because the drive from the blocks is also of a very short duration, we might expect to see more variability as they explode into action. The biomechanical variability in set positions for able-bodied athletes as documented by Mero (1988) and supports this interpretation.

There was variability in all biomechanical features of the set position for all four Paralympic athletes. This variability was small for Participants One, Two and Three. These three athletes were well into their sprinting careers the variability they displayed would be anticipated as part of their technique refinement over the course of the training year. However, the variability exhibited by Participant Four was noticeably greater. He was not simply adjusting his set position throughout the year, but rather was getting feedback from his coach in order to find a set position that would help him improve is initial acceleration phase. It is clear from the results that by the fourth test session, a set position had been found that produced the fastest time. This emphasizes that variability in the set position must be associated with adjustments to environmental circumstances, not with a lack of experience.

Research Question 1b

What variability can be observed in stride length and stride frequency during the initial acceleration phase over the course of a training year?

Variability in the sprint mechanics during the initial acceleration phase revealed important information for coaches of athletes with different disabilities. Although there was some variability within each athlete, there were also important differences noticed between the athletes with different disabilities.

A physical or sensory disability does present an individual constraint on motor performance. Fitts' law states that in order to be accurate, task performance needs to be slowed down to the point where the performer can control the movement variables (Lee, 2011). Exerting force to push themselves forward with maximal effort and into an optimal sprinting position may require that they propel themselves forward slightly slower until an optimal relationship between stride length and stride frequency is found. As motor control strategies become more stable, task performance can be speeded up. This is compatible with the progressive improvements in time and speed over the training year.

Each of the participants in this study brought different constraints to their sprinting performance. Their challenge was to determine how to manipulate stride length and stride frequency to manage these constraints in order to produce the fastest time by the end of the training year. Each athlete was successful in this, and the variability in their stride length and frequency throughout the year provide some focus points for coaches of Paralympic athletes.

For an athlete with a single leg amputation:

- Find the optimal length for the second stride (with the prosthetic leg) out of the blocks.
- Focus on finding the optimal stride length from the 3rd step to 10m.

For an athlete with a visual impairment:

- A shorter first stride and a longer second stride will help create a balanced and confident first two steps.
- Focus on finding the optimal stride frequency from the 3rd step to 10m.

For athletes with cerebral palsy:

- Find a stride length that can be managed consistently.
- Focus on finding the optimal stride length-stride frequency relationship that can be consistently controlled. Stride frequency may be the most practical coaching point.

Research Question 1c

What variability can be observed in stride length and stride frequency during the maximal running velocity phase over the course of a training year?

Variability in the sprint mechanics during the maximal running velocity phase also revealed important information for coaches of athletes with different disabilities. There were important differences noticed between the athletes with different disabilities in terms of coaching focus on either stride length or stride frequency.

For an athlete with a single leg amputation:

- Focus on finding the optimal stride length from 30m – 40m.

For an athlete with a visual impairment:

- Focus on finding a stride frequency that can be managed consistently from 30m-40m.

For athletes with cerebral palsy:

- Focus on finding a stride frequency that can be managed consistently from 30m-40m.

The focus on stride frequency for the three of the four athletes may be related to their disabilities. Athletes with visually impairments may not take as long a stride length as a coach might think optimal, because of their lack of sensory information about the environment has a limiting effect on their confidence and balance. The focus on increasing the turnover rate of the strides to improve their time and speed may be more productive. Some athletes with cerebral palsy may have muscle tone issues that make it difficult for them to increase their stride length, in which case increasing their stride frequency would be the key to improving their performance. An athlete with a below knee amputation presents a more “mechanical” set of constraints associated with his/her prosthesis. This agrees with the research of Buckley (1999) where he found that mechanics experienced by sprinters with amputations are dependent on the prosthesis worn.

When the findings of this study was compared to existing research, it was found that for athletes with a below knee amputation, this research agreed with the findings of Grabowski *et el.* (2009) and that these sprinters must focus on stride length to improve performance. When looking at the findings for athletes with visually impairments, this research, interestingly, disagreed with the findings of Arnhold and McGrain (1985) and that of Shumway-Cook and Woollacott (2007) concluding rather that stride frequency and not stride length was key for these athletes to improve performance. For athletes with cerebral palsy this research agreed with the study of Pope, Sherril, Wilkerson and Pyfer (1993) and concluded that stride frequency was key for these athletes.

Research Question Two

Does a rhythm training programme have the potential to influence the sprinting performance of a Paralympic athlete?

The rhythmic training implemented in this study was a six-week Interactive Metronome™ training programme. The premise of the programme was that it might improve the coordination of the participants and that this improvement in coordination would be evident in one or more of the selected kinematic variables, *e.g.* stride length and/or stride frequency, time of sprint and speed.

Research Question 2a – During the Initial Acceleration Phase

The potential of IM™ training on the initial acceleration phase is summarised in Table 18.

Table 18

Summary of the IM™ results for participants during the initial acceleration phase.

Participant & Class	Outcome for this Phase	Potential Contribution to the Initial Acceleration Phase
1 (T43)	Increase in stride length and stride frequency	Improved coordination of movement patterns (Koomer *et al.*, 2000).
2 (T13)	Increase in stride length and stride frequency	Improved execution of coordination patterns and rhythmicity of movement (Myskja, 2005).
3 (T37)	Increase in stride length and stride frequency	Optimise efficiency and effectiveness of movement (Sommer & Rönnqvist, 2009).
4 (T38)	Increase in stride length and stride frequency	Optimise efficiency and effectiveness of movement (Sommer & Rönnqvist, 2009).

Research Question 2b – During the Maximal Running Velocity Phase

The potential of IM training on the initial acceleration phase is summarised in Table 19.

Table 19

Summary of the IM™ results for participants during the maximal running velocity phase.

Participant & Class	Outcome for this Phase	Potential Contribution to the Maximal Running Velocity Phase
1 (T43)	Increase in stride length	Improved coordination of movement patterns (Koomer *et al.*, 2000).
2 (T13)	Increase stride frequency	Improved execution of coordination patterns and rhythmicity of movement (Myskja, 2005).
3 (T37)	Increase stride frequency	Optimise efficiency and effectiveness of movement (Sommer & Rönnqvist, 2009).
4 (T38)	Increase stride frequency	Optimise efficiency and effectiveness of movement (Sommer & Rönnqvist, 2009).

Perceptions of the Participants

The participants each shared their perceptions about the potential of IM training to affect their sprinting performance. These results are summarised in Table 20.

Reflections on the Potential of IM™ Training

All the participants in this study were competing at the elite level (the Train to Compete Stage) of the Long Term Athlete Development model (Bhambhani & Higgs, 2011). While all of the athletes enjoyed the IM™ experience and indicated they thought it had helped them in their sprint performance, only the least experienced and skilled of the group indicated that he would like to continue with IM™ training in the future. This introduces the possibility that IM™ training may have greater potential during some periods of athlete development than in others.

Table 20

Summary of participants' overall impression of the potential of IM™ training.

Participant & Class	Participant's Overall Impression
1 (T43)	Felt a positive impact of the training but felt that more training would not be beneficial
2 (T13)	Felt a positive impact of the training but felt that more training would not be beneficial
3 (T37)	Felt a positive impact of the training but felt that more training would not be beneficial
4 (T38)	Felt a positive impact of the training and felt that more training would be beneficial

The optimal ages for skill development for able-bodied youth have been identified as ages 8 – 11 for females and 9 – 13 for males, based on peak height velocity estimates (Bhambhani & Higgs, 2011). These become the optimal times for laying down coordinative structures. It is possible that this would be a better time to introduce the type of rhythmic training associated with IM™ training. In fact, most of the research with the Interactive Metronome has been completed with children. Although Bhambhani and Higgs (2011) were clear in their statement that no differences have been found between youth with disabilities and their able-bodied peers in terms in terms of these periods, they did emphasise that developmental age rather than chronological age was the key to identifying periods for optimal development.

Children with visual impairments tend to have a slower and more extended development, which would impact the ages of optimal development of skill, speed, etc. (Halliday, 1970). Because physical growth is not impacted by a visual impairment, the impairment would not change the shape of the peak height velocity curve, but rather might change the rate at which children develop their motor skills. The challenge for coaches is to find ways to accelerate the motor skill developmental of children with visual impairments so that is approximates that of fully-sighted children.

No research was found on optimal periods for sport development for youth with cerebral palsy. Because cerebral palsy is an impairment of the central nervous system, it could be speculated that the acquisition of effective coordinative structures is a special challenge that must be considered in reference to the specific type and severity of cerebral palsy and the specific task and environmental constraints of the sport. It is not unreasonable to think that rhythm training would be helpful in many cases, even if it is more appropriate for beginning and intermediate rather than elite level athletes.

Amputations become an entirely different consideration. For example, if the amputation has occurred after growth and substantial motor skill development has already occurred, then the challenge is to incorporate the “new” physical constraint into previously established coordinative structures. Depending on the specific amputation, whether or not a prosthetic is involved, the demands of the task, etc., coordination re-training might be helpful. It this case, an intervention such at the IM™ training might provide support for re-setting the coordinative structures, especially in terms of the rhythms underlying gait (walking and running).

Conclusions

Based on the results of this study and within the limitations presented when conducting case study research with elite level athletes over the course of a full training year, the following conclusions are drawn:

1. Elite level Paralympic athletes are as unique as any other elite level athlete. For example, research has shown that athletes with below knee amputations often struggle with stride length, tend to have very short strides and have a tendency to have a slow stride frequency and poor balance (Cugini, Bertetti & Bonacini, 2006). The elite level Paralympic sprinter in this study did not fit this profile.

2. Because the prosthesis of an athlete with an amputation is a task constraint, coaches should try to incorporate the prosthesis into all coordination and motor training to try diminishing its effects as much as possible. The amputation and prosthesis while not affecting the central

nervous system, will affect the body schema, which will in turn affect the movement coordination and rhythm, which are control parameters (Davids *et al.*, 2008). The challenge presented with a sprinting prosthesis is that it is designed. Coaches should endeavour to have these athletes run at an optimal stride length while still maintaining a high stride frequency.

3. The majority of athletes with visual impairments have experienced developmental delays in the areas of gross motor skills and perception (Freeman *et al.*, 2007) which could have an enduring impact on the stability of their coordinative structures. Coaches should try assist these athletes develop a good sense of balance and have them try improve their stride frequency to a higher more optimal level.

4. The Paralympic athlete with a visual impairment in this study experienced a progressive degeneration in her vision and did not manifest any developmental delays. Once again, the need to regard each athlete as unique is evident.

5. Research has shown that athletes with cerebral palsy typically have some form of impaired movement in ambulation that involves gait and upper body coordination, as well as problems with balance (Kwak, 2007). The severity of the disability and the type of cerebral palsy need to be considered when working with these athletes. With the knowledge that the athletes with cerebral palsy will have some limitation to their central nervous system and that this limitation may be manifested with substantial changes to the coordination and movement patterns, and with rhythm being a control parameter to sprinting, coaches will need to customise training to optimise the abilities of this athlete (Davids *et al.*, 2008). Coaches should encourage these athletes to strive to attain a high stride frequency with their best stride length in order to be successful.

6. If one considers that rhythm training such as the IM™ intervention might be beneficial during optimal periods of skill development (either during

childhood or as part of initial re-learning of skills), then there could also be optimal periods during the training year when rhythm training is beneficial and other periods when it is not. Practical considerations in the delivery of the programme in this study put this training during the athletes' pre-competition phase. This was an advanced period in the training year and implementation of rhythm training could have been more beneficial if it had been delivered in the first preparation phase in the beginning of their training year. Despite this there were positive subjective responses from all the participants to the IM™ training. Only one participant thought that a longer rhythmic training period would generate more positive results.

Recommendations

For Coaches

A productive way for coaches to start thinking about how to respond to the challenges of coaching athletes with disabilities is to adopt a dynamic systems approach where the unique individual constraints presented by the impairment interact with the task (in this case running) and the environmental constraints. Variability has historically been considered to be detrimental to performance (Bradshaw *et al*., 2007) and traditional coaching models have attempted to make their athlete's invariant in their sprint biomechanics. However, with the sprint start being a maximal effort movement (Harland & Steele, 1997), recent research has shown that some flexibility in the athlete's sprint biomechanics might be more advantageous to their performance (Knight, 2004). With this flexibility, the athlete can adjust to numerous intrinsic factors, such as confidence and fatigue, and extrinsic factors, such as wind and temperature, which could otherwise influence their performance (Bradshaw & Aisbett, 2006). This approach is further strengthened when looking at the dynamical systems theory which says that for a consistent high-standard performance across various conditions, a flexible joint coordination pattern must be used that can be adapted to suit the demands of the task at hand (Bradshaw *et.al.*, 2007).

In the study by Bradshaw *et.al.* (2007), they found that when there was a decrease in the initial acceleration phase time, there was an increase in biomechanical variability. They established a link between improvements in overall sprint performance when a more variability in the sprint action was observed. Furthermore, they found a link between the reduction in joint coordination variability and an increase in the rate of injuries. The dynamical systems theory may explain this association, with low joint coordination variability resulting in the same tissues being continually loaded during a specific activity (Nigg, 1988). By developing optimal joint coordination variability, sprinters may reduce their risk of acute and overuse injuries as well as improve their consistency and performance.

Coaches could start using easily accessible technology, such as video analysis software, to assist them with a data gathering and monitoring process throughout the year. This information could help them to better customise their training sessions to the unique needs of their different athletes.

For Research

There is a tremendous amount of research that needs to be done in disability sport, and specifically at the elite levels. For example, a study by Thomas, Zebas, Bahrke, Araujo and Etheridge (1983) found that over 80% of variance in trials of sprinters could be related to psychological factors. In other words, when the athletes performed better, it was usually because they were in a psychological state that made them believe they could. Would these findings be similar for Paralympic sprinters?

In terms of future research about sprinting using video analysis, several suggestions are made:

1. Higher frequency (a minimum of 100hrz) cameras) could be used that would produce more frames per second which would create a clearer more accurate image for precise analyses.
2. The use of force plates, both in the starting blocks and on track, would provide valuable information about possible force generation and the ground reaction forces applied. This could help provide clearer concepts of the total body coordination.

3. Cameras set in two planes will provide a more three dimensional model of the sprint performance and assist in making any conclusions and deductions more accurate.
4. Conducting a longitudinal study looking at the changes in variability using more sophisticated measuring instrumentation would provide more insight into the training of high performance athletes with disabilities.

In terms of future research with the IM™ system, several suggestions are made:

1. Study participants less than 13 years old who are in a less stable phase of sprinting skill development. This will produce insights into the potential of the IM™ system to encourage rhythmical and coordinated movements.
2. Study participants from different disability groups, in particular cerebral palsy, to determine if IM™ training has any effects on their sprinting gait (stride length and stride frequency).
3. Expand the number participants who engage in IM™ system during a pre-training phase and utilise more sophisticated video analysis to determine any changes in rhythm or coordination in sprinting.
4. Conduct a study specifically looking at the effect that the IM™ training will have on the intra-limb coordination of sprinters.

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Appendix A

Informed Consent

Reference number:_____

INFORMED CONSENT

Project: Sprinting Kinematics of Athletes with Selected Physical Disabilities and the effect of the Interactive Metronome Training on these Kinematics

Consent of the Participant:

I, ________________________________(ID:________________________________)

From (address)____

____

____

Confirm that:

1. I was invited to participate in the above-mentioned project conducted by Barry Andrews (BSc Masters Sport Science) from the Department of Sport Science at Stellenbosch University. I am aware that the results will be used for his PhD. thesis and subsequent research presentations. I volunteered to participate in this study.

2. It was explained to me that:

2.1. The aim of the project is to determine my sprint kinematics through the use of video recordings.

2.2. I will participate in two 60m sprint races, for each of the pre-tests and post-test. During each race, I will run alone and my sprint kinematics will be recorded for later analysis.

2.3. I will also make myself available for the intervention study on the affects of the computer based Interactive Metronome training system.

2.4. I will partake in the Interactive Metronome training twice a week for the period of the intervention study.

3. Potential risks and discomforts

3.1. No invasive procedures or administrations of any substances will be occurring.

3.2. I understand that if I experience any discomfort at any time during the testing, I may stop.

4. Potential benefits

4.1. The results of this study will add to the understanding of both the sprint kinematics of physically disabled athletes and the impact of disabilities of sprint kinematics and how athletes with disabilities can participate with able-bodied athletes without having any advantage over or disadvantage to them in any way.

4.2. It will add people's understanding of the use of Interactive Metronome training methods for elite athletes.

5. Payment for participation

5.1. I will not be paid for my participation in this study.

6. Confidentiality

6.1. Any information that is obtained in connection with this study and that can be identified as my data will remain confidential and will be disclosed only with my permission or as required by law. Confidentiality will be maintained by means of assigning a code number to my data. Thereafter, all data for me will be identified by that code. The master list of participants and their code numbers will be stored in a locked cabinet in the Disabilities Laboratory. The researcher is the only person who has access to this cabinet.

6.2. The results from all participants will be combined for the generation of the tables of normative values for each kinematic variable, which will be published in the PhD. thesis. It is also intended to publish these findings in an accredited journal. There will be no specific reference to any individual's performance in these publications.

6.3. If there is ever any occasion when the performance of individual subjects is made, reference will only be made by code number, never by name.

Participation and withdrawal

6.4. I can choose whether to be in this study or not. If I volunteer to be in this study, I may withdraw at any time without consequence of any kind. The researcher may withdraw me from this research if circumstances arise which warrant doing so.

7. Identification of investigators

7.1. If I have any questions or concerns about the research, I may contact:

Barry Andrews:
5 Stephen Rd, Tokai, Cape Town 7945
Cell: 082 658-1552
Fax: 086 556 4401
Email: andrewsbarry@gmail.com

Promoter: Prof. ES Bressan
Department of Sport Science
Stellenbosch University
Phone: 021 808-4722
Fax: 021 808-4817
Email: esb@sun.ac.za

8. Rights of research subjects

8.1. I may withdraw my consent at any time and discontinue participation without penalty. I am not waiving any legal claims, rights or remedies because of my participation in this research study. If I have any questions regarding my rights as a research subject I can contact Ms Maléne Fouché (mfouche@sun.ac.za; 021 808 4622) at the Unit for Research Development of Stellenbosch University.

9. The above information was explained to me by Barry Andrews in

□ English

□ Afrikaans

and I am in command of this language.

I was also given an opportunity to ask questions and all my questions were answered satisfactorily.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

____

Name of Subject/Participant

____

Signature of Subject/Participant or Legal Representative

Signed at ________________________ on _____________ 20__

STATEMENT OF THE RESEARCHER

I, Barry Andrews, declare that I:

1. Explained the information contained in this document to _______________
2. Requested the participant to ask questions if anything was unclear.
3. Performed this conversation in either English or Afrikaans after determining that the participant was in command of this language.

Signed at __________________________ on __________________ 20__

Barry Andrews: ___________________________
Signature

Appendix B

Additional Programme Details

IM Data Explained

- The content of the SFA

  The SFA is a two-minute evaluation tool consisting of two tasks Task 1 – Both hands, and Task 2 – Both hands with guide sounds). It is ideally suited for briefly assessing the patient at the beginning and/or end of each treatment session in the areas of motor, attention, and sensory processing skills.

- The content of the LFA

  The LFA is a 20 to 30 minute evaluation that provides objective baseline data regarding the patient's ability to motor plan/sequence, attend and process auditory and sensory information. It measures progress and provides objective data for reporting purposes and it allows for continuous monitoring of effectiveness of treatment approach.

- The content of the Attend over time assessment

  The Attend Over Time assessment is an excellent complement to the LFA. It measures the patient's ability to sustain attention and tolerate sensory stimulation over a longer period (500repititions or 9.7 minutes).

- Tempo

  Displays the rate (beats per minute) of the reference tone. The default setting is 54 beats per minute.

- Difficulty

  Indicates the millisecond range within which the individual will hear only the 'Super-Right-On', 'Early' and 'Late' guide sounds.

Appendix C

Participants' Full Kinematic Data

The tables that follow show the kinematic data for each participant, highlighting their stride length (SL) in meters, stride frequency (SF) in strides per second, time (T) in seconds, speed (Sp) in meters per second, and acceleration (Acc) in meters per second squared.

Participant One

Table B1

Initial acceleration kinematic data for Participant One

	Pre-Test 1		**Pre-Test 2**		**Pre-IM Test 3**		**Post-IM Test 4**		**Mean**	**SD**	**V**
	1st Trial	**2nd Trial**	**1st Trial**	**2nd Trial**	**1st Trial**	**2nd Trial**	**1st Trial**	**2nd Trial**			
1st SL	0.69	0.68	0.70	0.67	0.69	0.71	0.70	0.67	0.69	0.01	0.00
2nd SL	1.18	1.14	1.20	1.10	1.05	1.14	1.24	1.17	1.15	0.06	0.00
Ave SL (3^{rd}-10m)	1.56	1.48	1.49	1.52	1.54	1.55	1.58	1.55	1.53	0.04	0.00
SF	2.85	2.80	2.92	2.94	2.89	2.92	2.94	2.94	2.90	0.05	0.00
T@5m	1.49	1.52	1.52	1.48	1.30	1.36	1.26	1.34	1.41	0.11	0.01
T@10m	2.20	2.40	2.21	2.08	2.10	2.18	2.02	2.12	2.16	0.12	0.01
Sp@5m	3.36	3.29	3.29	3.38	3.85	3.68	3.97	3.73	3.57	0.27	0.07
Sp@10m	4.55	4.17	4.52	4.81	4.76	4.59	4.95	4.72	4.63	0.24	0.06
Acc@10m	2.07	1.74	2.05	2.31	2.27	2.10	2.45	2.22	2.15	0.22	0.05

Table B2

Maximal running velocity kinematic data for Participant One

	Pre-Test 1		Pre-Test 2		Pre-IM Test 3		Post-IM Test 4		Mean	SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial			
Ave SL	2.04	2.01	2.12	2.14	2.24	2.27	2.27	2.33	2.18	0.12	0.01
SF	3.77	3.97	3.70	3.91	3.70	4.03	3.70	4.03	3.85	0.15	0.02
T	1.05	1.12	1.10	1.12	1.18	1.20	1.10	1.04	1.11	0.06	0.00
Ave Sp	9.52	8.93	9.09	8.93	8.47	8.33	9.09	9.62	9.00	0.45	0.20
Acc	9.07	7.97	8.26	7.97	7.18	6.94	8.26	9.25	8.11	0.80	0.65

Participant Two

Table B3

Initial acceleration kinematic data for Participant Two

	Pre-Test 1		Pre-Test 2		Pre-IM Test 3		Post-IM Test 4		Mean	SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial			
1st SL	0.38	0.55	0.45	0.42	0.55	0.34	0.58	0.49	0.47	0.09	0.01
2nd SL	1.10	1.08	1.10	1.10	1.10	1.11	1.18	1.24	1.13	0.05	0.00
Ave SL (3^{rd}-10m)	1.42	1.46	1.45	1.44	1.47	1.45	1.53	1.49	1.46	0.03	0.00
SF	3.17	3.15	3.24	3.17	3.30	3.24	3.25	3.47	3.25	0.10	0.01
T@5m	1.49	1.47	1.42	1.50	1.32	1.38	1.38	1.26	1.40	0.08	0.01
T@10m	2.23	2.22	2.16	2.23	2.12	2.18	2.12	2.02	2.16	0.07	0.01
Sp@5m	3.36	3.40	3.52	3.33	3.79	3.62	3.62	3.97	3.58	0.22	0.05
Sp@10m	4.48	4.50	4.63	4.48	4.72	4.59	4.72	4.95	4.63	0.16	0.03
Acc@10m	2.01	2.03	2.14	2.01	2.22	2.10	2.22	2.45	2.15	0.15	0.02

Table B4

Maximal running velocity kinematic data for Participant Two

	Pre- Test 1		Pre- Test 2		Pre-IM Test 3		Post-IM Test 4		Mean	SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial			
Ave SL	2.20	2.16	2.10	2.12	2.07	2.12	1.91	1.89	2.07	0.11	0.01
SF	3.88	4.07	4.13	3.90	3.79	3.90	4.10	4.27	4.00	0.16	0.03
T	1.24	1.23	1.21	1.23	1.32	1.32	1.22	1.20	1.25	0.05	0.00
Ave Sp	8.06	8.13	8.26	8.13	7.58	7.58	8.20	8.33	8.03	0.29	0.09
Acc	6.50	6.61	6.83	6.61	5.74	5.74	6.72	6.94	6.46	0.47	0.22

Participant Three

Table B5

Initial acceleration kinematic data for Participant Three

	Pre- Test 1		Pre- Test 2		Pre-IM Test 3		Post-IM Test 4		Mean	SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial			
1st SL	0.63	0.61	0.61	0.72	0.59	0.62	0.81	0.78	0.67	0.09	0.01
2nd SL	1.14	1.16	1.22	1.14	1.22	1.18	1.31	1.26	1.20	0.06	0.00
Ave SL (3^{rd}-10m)	1.58	1.59	1.57	1.52	1.55	1.59	1.59	1.50	1.56	0.03	0.00
SF	3.27	3.27	3.38	3.40	3.37	3.22	3.49	3.57	3.37	0.12	0.01
T@5m	1.43	1.43	1.32	1.36	1.36	1.44	1.32	1.34	1.38	0.05	0.00
T@10m	2.14	2.15	2.07	2.09	2.08	2.20	1.96	2.02	2.09	0.08	0.01
Sp@5m	3.50	3.50	3.79	3.68	3.68	3.47	3.79	3.73	3.64	0.13	0.02
Sp@10m	4.67	4.65	4.83	4.78	4.81	4.55	5.10	4.95	4.79	0.18	0.03
Acc@10m	2.18	2.16	2.33	2.29	2.31	2.07	2.60	2.45	2.30	0.17	0.03

Table B6

Maximal running velocity kinematic data for Participant Three

	Pre-Test 1		Pre-Test 2		Pre-IM Test 3		Post-IM Test 4		Mean	SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial			
Ave SL	2.09	2.06	2.09	2.04	2.09	2.01	2.05	2.10	2.07	0.03	0.00
SF	3.70	3.70	3.70	3.66	3.70	3.42	3.69	3.77	3.67	0.11	0.01
T	1.08	1.09	1.08	1.18	1.08	1.36	1.14	1.06	1.13	0.10	0.01
Ave Sp	9.26	9.17	9.26	8.47	9.26	7.35	8.77	9.43	8.87	0.69	0.48
Acc	8.57	8.42	8.57	7.18	8.57	5.41	7.69	8.90	7.92	1.16	1.34

Participant Four

Table B7

Initial acceleration kinematic data for Participant Four

	Pre-Test 2		Pre-IM Test 3		Post-IM Test 4		Mean	SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial			
1st SL	0.56	0.55	0.56	0.55	0.87	0.82	0.65	0.15	0.02
2nd SL	1.24	1.26	1.28	1.26	1.31	1.30	1.28	0.03	0.00
Ave SL (3^{rd}-10m)	1.50	1.55	1.60	1.56	1.62	1.53	1.56	0.04	0.00
SF	3.11	3.01	3.21	3.02	3.50	3.42	3.21	0.21	0.04
T@5m	1.53	1.56	1.46	1.50	1.28	1.34	1.45	0.11	0.01
T@10m	2.25	2.28	2.18	2.22	2.00	2.02	2.16	0.12	0.01
Sp@5m	3.27	3.21	3.42	3.33	3.91	3.73	3.48	0.28	0.08
Sp@10m	4.44	4.39	4.59	4.50	5.00	4.95	4.65	0.26	0.07
Acc@10m	1.98	1.92	2.10	2.03	2.50	2.45	2.16	0.25	0.06

Table B8

Maximal running velocity kinematic data for Participant Four

	Pre-Test 2		Pre-IM Test 3		Post-IM Test 4		Mean	SD	V
	1st Trial	2nd Trial	1st Trial	2nd Trial	1st Trial	2nd Trial			
Ave SL	2.05	2.01	2.02	2.07	1.99	1.98	2.02	0.03	0.00
SF	4.20	4.30	4.55	4.46	4.55	4.50	4.43	0.14	0.02
T	1.19	1.21	1.10	1.12	1.10	1.14	1.14	0.05	0.00
Ave Sp	8.40	8.26	9.09	8.93	9.09	8.77	8.76	0.35	0.12
Acc	7.06	6.83	8.26	7.97	8.26	7.69	7.68	0.61	0.37