IAAF Sprint Start Research Project: Is the 100 ms limit still valid?

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ABSTRACT

The current false start criterion used by the IAAF is based on an assumed minimum auditory reaction time. If an athlete moves sooner than 100 ms after the start signal, he/she is deemed to have false-started. The purpose of this study, which was commissioned by the IAAF, was to examine neuromuscular reaction to the auditory signal used in the sprint start and to determine whether the 100 ms limit is correct. Seven national-level Finnish sprinters took part. A comprehensive approach was used to study force reaction on the blocks, the movements of the arms and the activation profiles of several muscles. The authors found great variation in individual reaction times and confirmed previous reports of simple auditory reactions as fast as 80 ms. They recommend that the 100 ms limit be lowered to 80 or 85 ms and that the IAAF urgently examines possibilities for detecting false starts kinematically, so that judges' decisions are based on the first visible movement regardless of the body part. This can be done with a system of high-speed cameras, which gives views of all the athletes on the start line. With such a system, it would be possible to change the start rule so that no false starts are permitted.

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Introduction

Speed of reaction is a critical aspect of many competitive sports, including the sprint events in athletics. In these events, the reaction time is considered to be the time taken by the athlete to respond to the start signal and begin pushing the starting blocks. A simple auditory reaction such as this is one of the fastest types of reaction, although it is thought to be rarely less than 100 ms (THOMPSON et al., 1992). It is noteworthy that this "definition" of reaction time specifically focuses on the force production on the blocks without necessarily referring to

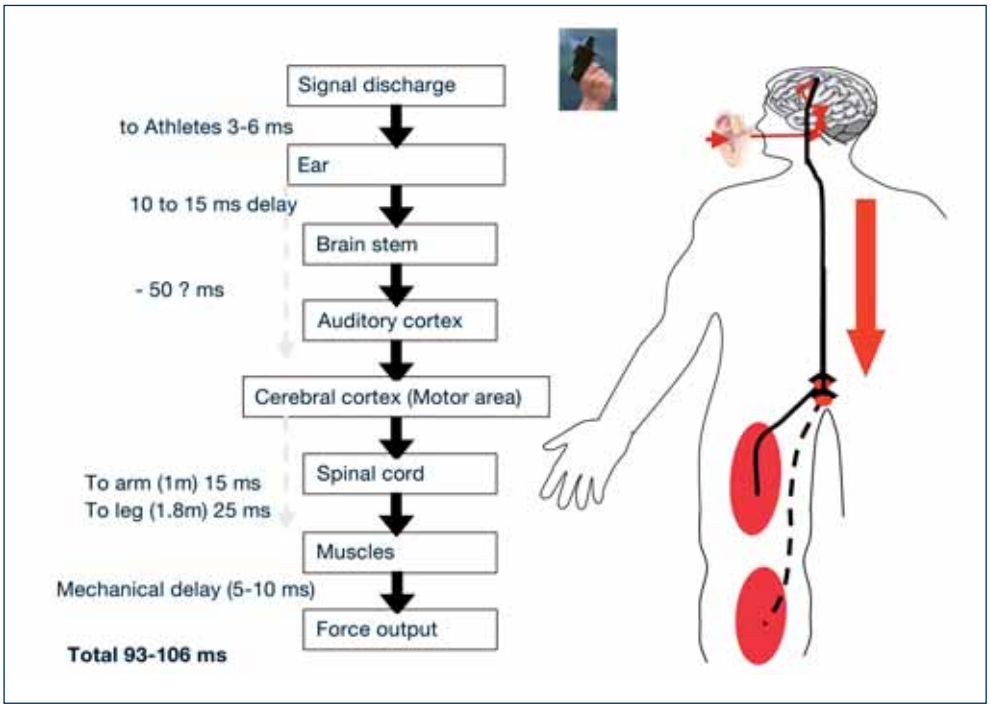

Figure 1: Sequence of the auditory evoked reaction

movements or force production of other body parts, such as head, neck, trunk or arms.

Physiologically, reaction time depends on several factors: arrival of the start signal stimulus at the sensory organ, conversion by the sensory organ to a neural signal, neural transmissions and processing, muscular activation, soft tissue compliance and the selection of the external measurement parameter (Figure 1). Each of these factors has an associated processing time that contributes to the overall reaction time.

The current false start criterion used by the International Association of Athletics Federations is based on an assumed minimum auditory reaction time of 100 ms (IAAF, 2003). If an athlete moves sooner than 100 ms after the start signal, the firing of the starter's gun, he/she is deemed to have false-started. Until recently, the reaction movement was deemed to have started when the threshold of 25kg of force above the baseline in the set position was reached on either of the blocks. This has now been changed so the reaction movement is judged by the steepness of the rise of the force curve.

These criteria seem to consider that all the human beings will have more or less similar results to an auditory reaction test, such as the sprint start. However, the influence of auditory stimulus on the initiation of complex motor tasks is not fully understood. There are several studies showing that simple auditory reaction times of less than 100 ms can be achieved (MERO & KOMI, 1990; ROTHWELL & VALLS-SOLE, 2002; PAIN & HIBBS, 2007; BROWN et al., 2008).

The purpose of the present study was to examine the neuromuscular reaction to the auditory signal used in the sprint start and to determine whether the current 100 ms limit is still justified. A comprehensive approach was

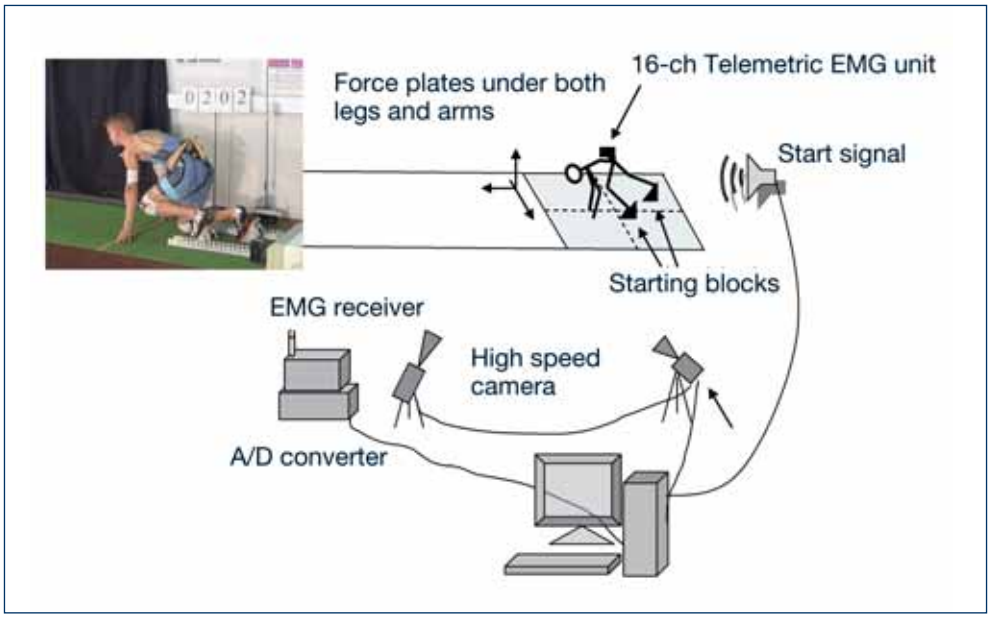

Figure 2: Schematics of the sprint start measurement

used to study the force reaction on the blocks and, using sophisticated EMG and kinematic approaches, the movements of the arms and the activation profiles of several muscles during the start movement.

Methods

Protocols

Seven Finnish national-level sprinters (four males and three women: age 24 ± 3 years; mass 71.2 ± 14.2kg; height 177 ± 7cm) participated in this study. They had previously been informed of the procedures and all the associated risks and all gave written consent. The measurements were included in the athletes' training and testing programmes as planned by their individual coaches.

The study was conducted in the biomechanics laboratory of the Neuromuscular Research Center, Department of Biology of Physical Activity, University of Jyväskylä. This laboratory is equipped, among other things, with a unique 10m long force platform system, composed of two rows of 1m long individual force plates placed in series, row by row. The force plate area continued as a free space for an additional 40m. Thus, the athletes were able to perform the start naturally, like in a real sprint competition. The force plate and the extended 40m are covered with tartan surface.

In the measurements, the athletes performed a total of five to eight sprint starts similar to the real race starts. Thus the conditions were as close as possible to real competitions. Figure 2 depicts how the starting bocks were positioned on the force-plates. The two individual front and rear start blocks were measured separately for both vertical (Fz) and horizontal (Fy) components of the ground reaction forces. Similar measurements were performed for the arm actions, again in the Fz and Fy directions.

Parameters

In addition to the recording of the Fz and Fy ground reaction forces (right and left sides) individually for both legs and arms using the

force plates, electromyogram (EMG) activities from the *erector spinae* (ES), *vastus medialis* (VM), *soleus* (SOL) and *tibialis anterior* (TA) muscles of both legs were recorded using bipolar miniature-size surface electrodes (diameter 6mm, interelectrode distance 21mm; Blue Sensor N-00-S/25, Medicotest, Olstykke, Denmark). These EMG data were amplified using the EMG telemetric recording system (bandwidth 10Hz to 1kHz per 3dB; model 16-2, ElSA, Freiburg, Germany) and were stored simultaneously together with kinetic data on a personal computer via an AD converter (Sampling rate 2kHz; Power 1401, Cambridge Electronics Design Ltd, England).

To determine when the initial reactions to the start signal took place, all start movements were video-recorded with two high-speed cameras at 300 fps (A600, Basler AG, Ahrensburg, Germany) from the rear leg side and from the 45º diagonally forward direction. Reflective markers were placed on the head, shoulder, elbow, hand, *trochanter major*, centre of rotation of the knee, *lateral malleolus*, heel, and fifth metatarsal head. These points were then digitised automatically (Motus, Vicon Peak Performance, USA) and used to determine the onset of the initial start movement.

An electronic pulse from the set to the start gun firing was used to synchronise the kinetic, kinematics, and EMG data.

Analyses

EMG signals were first full-wave rectified and then filtered (Butterworth 4-order low-

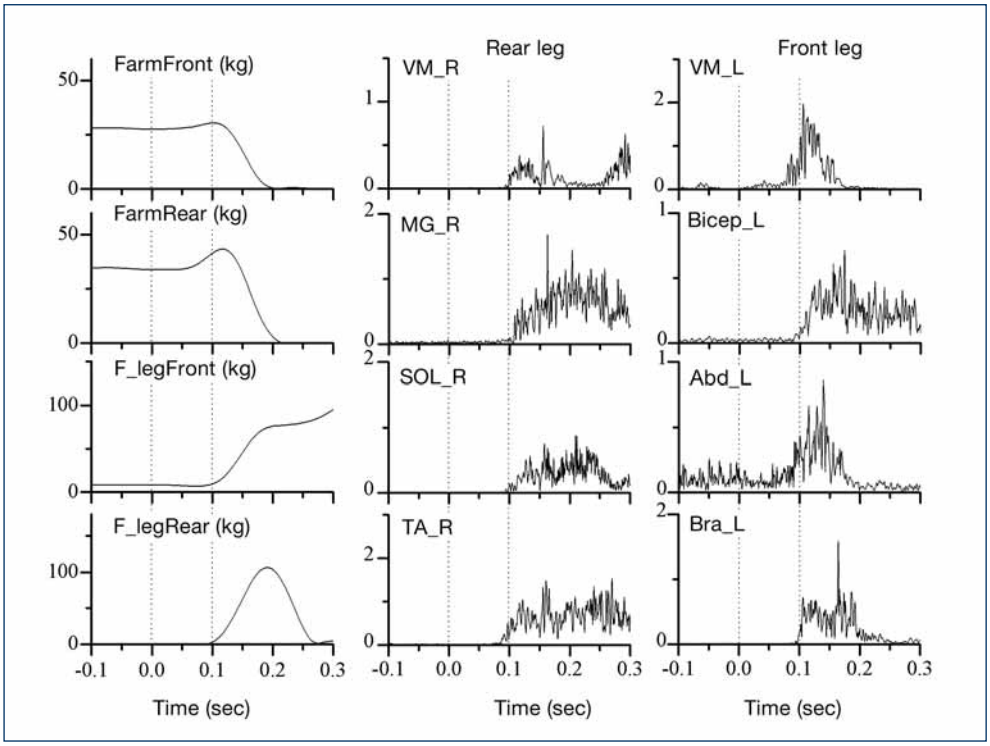

Figure 3: Time course data of the kinetics (arm and leg forces) and EMGs during the sprint start (The zero (first dotted line) is the onset of the start signal.) VM=vastus medialis, MG=medial gastrocnemius, SOL=soleus, TA=tibialis anterior, Bicep=biceps femoris, Abd=rectus abdominis, Bra=brachioradialis

Table 1: Reaction times (ms)

	Mean (SD)	Fastest (SD)
Kinetics		
Onset of leg force reaction	98 (23)	78 (27)
Onset of arm force reaction	69 (12)	49 (14)
Force detection (25kg level)	133 (21)	114 (29)
Kinematics		
Head movement	110 (17)	101 (21)
Hand movement	108 (20)	104 (17)
EMG		
Erector spinae	87 (33)	69 (30)
Vastus medialis	94 (16)	73 (19)
Medial gastrocnemius	96 (20)	82 (26)
Soleus	112 (20)	91 (17)
Tibialis anterior	74 (18)	59 (13)

** time from the auditory stimulus (n=7)*

pass filter: 75Hz). The onset of EMG was determined by visual inspection of the filtered EMG signal with the researcher deciding when the signal had changed from baseline during the set position.

The resultant force during the start movement was calculated from Fz and Fy data for determining the onset and the 25kg threshold of the rise of the resultant force curve.

Values are presented as means and standard deviations (SD) unless otherwise stated.

Results

Figure 3 shows a typical example of the time course of the force and EMG data during the sprint start. Table 1 gives the mean and fastest reaction times for each parameter. The onset of the arm force reaction (69 ms) was faster than that of the leg force reaction (98 ms). The time to reach the force detection level (25kg) delayed the reaction time by approximately 35 ms compared to the onset of the leg force reaction. In the fastest start condition, the onset of the muscle activation for the measured EMGs occurred earlier than in 100 ms.

In the 25kg force level detection, three subjects (subject02, subject04, subject07) had reaction times less than 100 ms in their fastest trial (Figures 4.1 to 4.7). Subject 7 showed mean reaction times of less than 100 ms although the timing of her 25kg force detection level was not fast due to the slow force development.

After the start signal, the head and wrist began to move at 110 ms and 108 ms, respectively (Table 1). Note the large standard deviations (17 and 20). The legs began to move after the head and wrist movements.

Discussion

The main results of this study are as follows:

1. In response to the start signal, the mean reaction time on the blocks required to reach the 25kg force level was generally longer than 100 ms. However, in several trials three subjects did have reaction

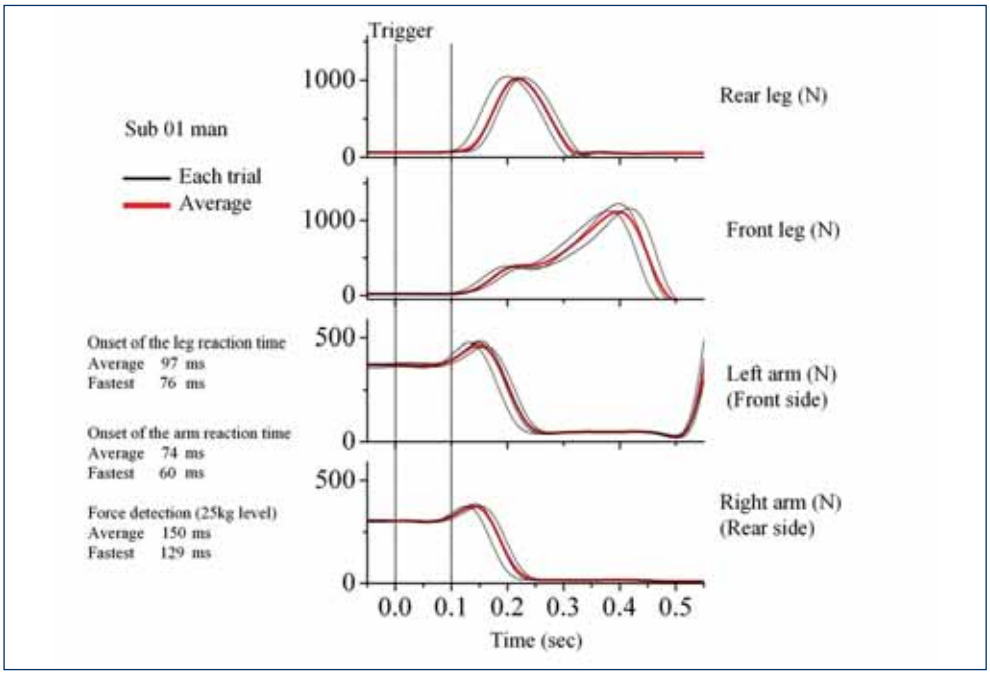

Figure 4.1: The time course data of the resultant forces for the arms and legs of subject 01

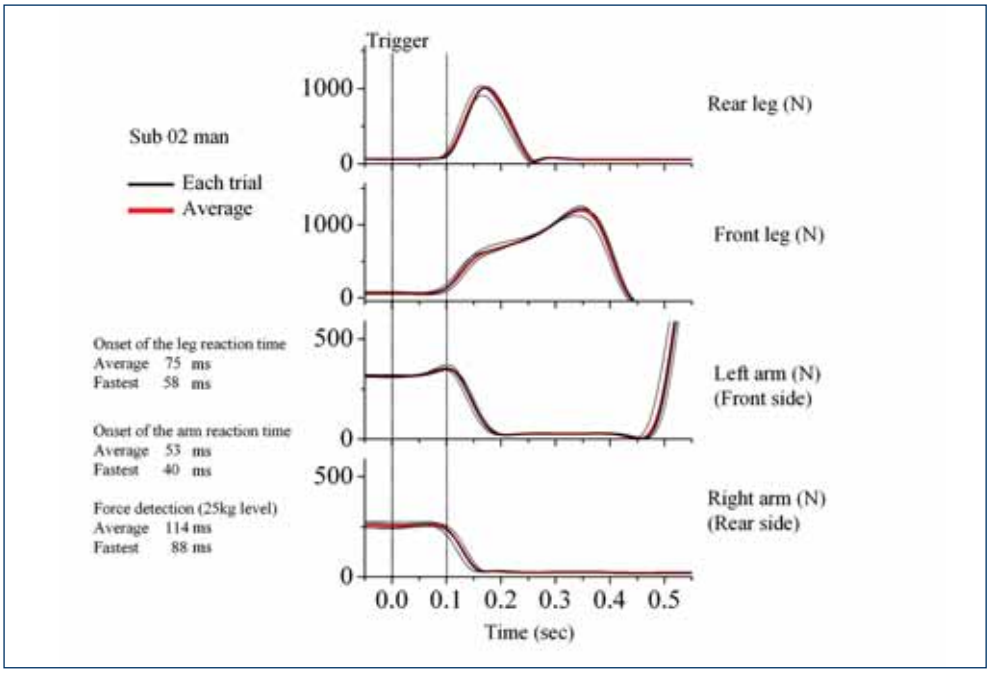

Figure 4.2: The time course data of the resultant forces for the arms and legs of subject 02

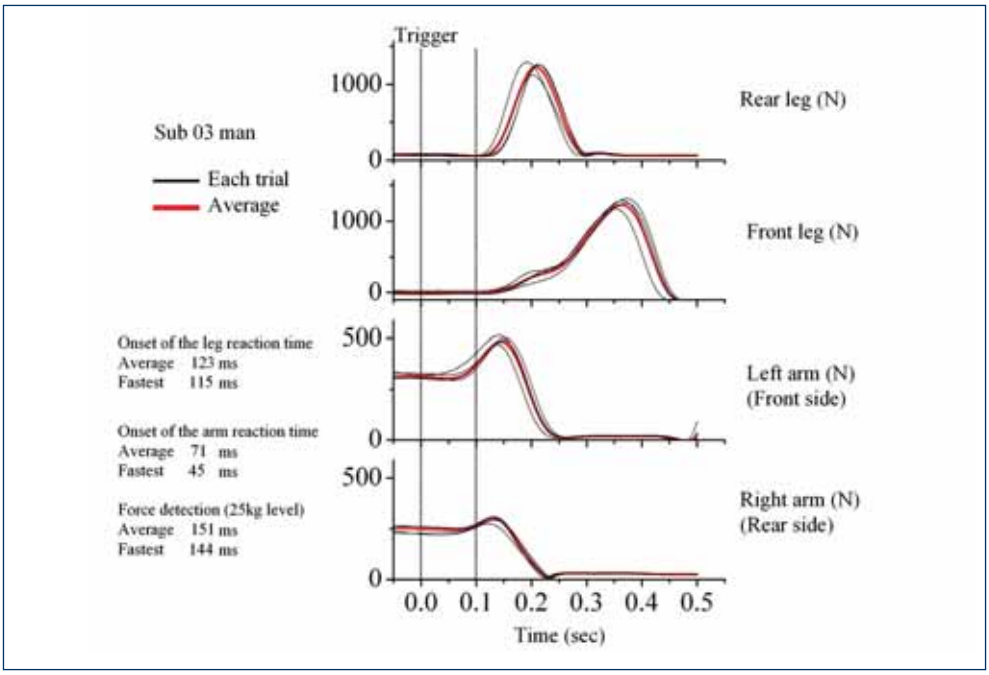

Figure 4.3: The time course data of the resultant forces for the arms and legs of subject 03

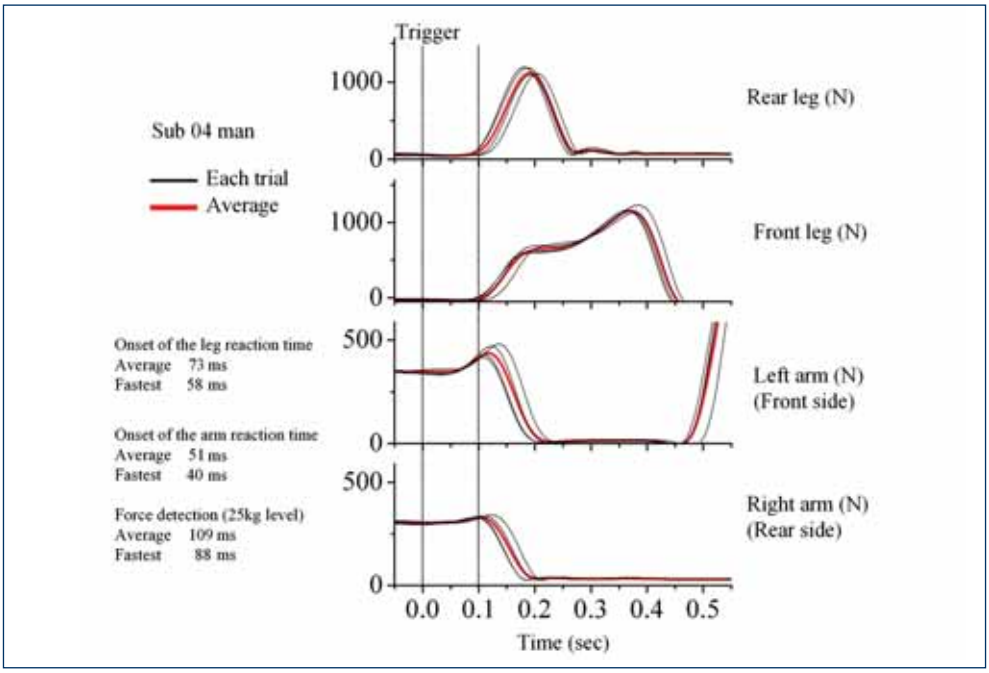

Figure 4.4: The time course data of the resultant forces for the arms and legs of subject 04

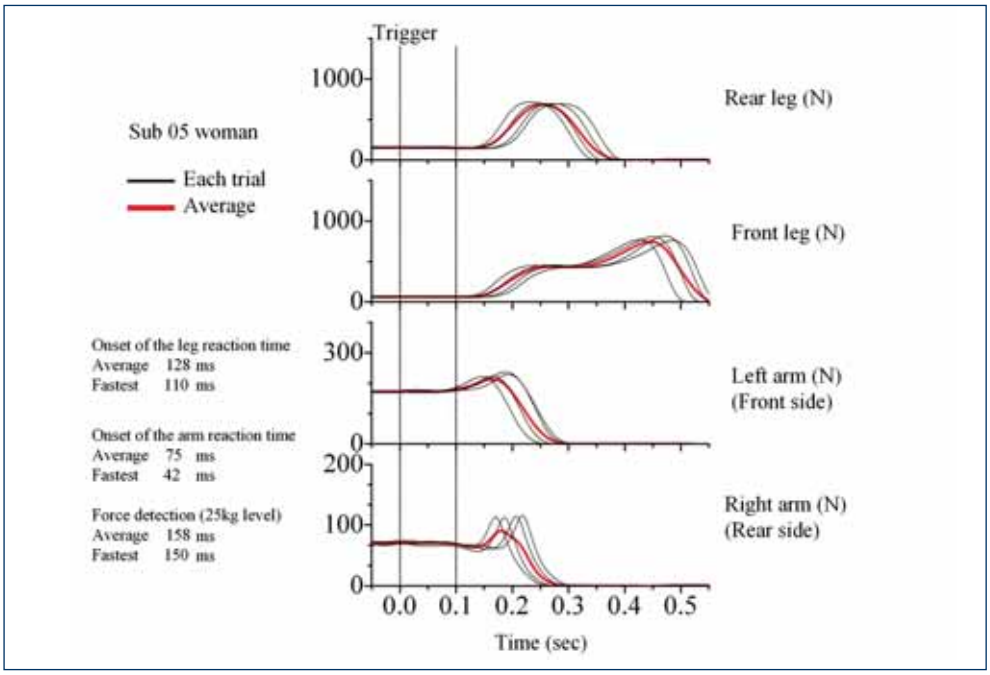

Figure 4.5: The time course data of the resultant forces for the arms and legs of subject 05

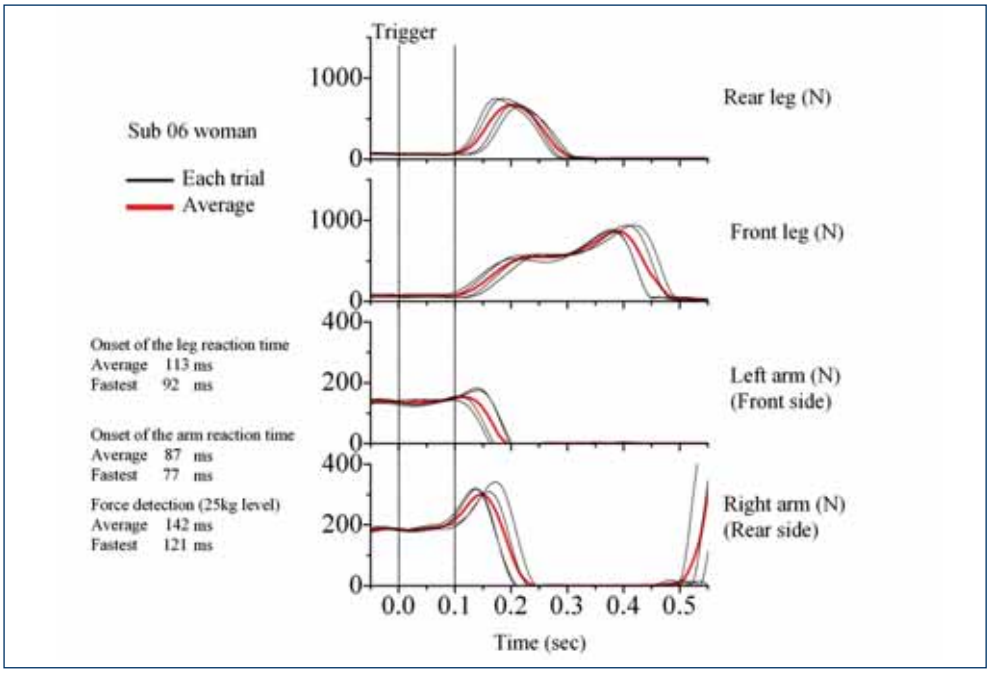

Figure 4.6: The time course data of the resultant forces for the arms and legs of subject 06

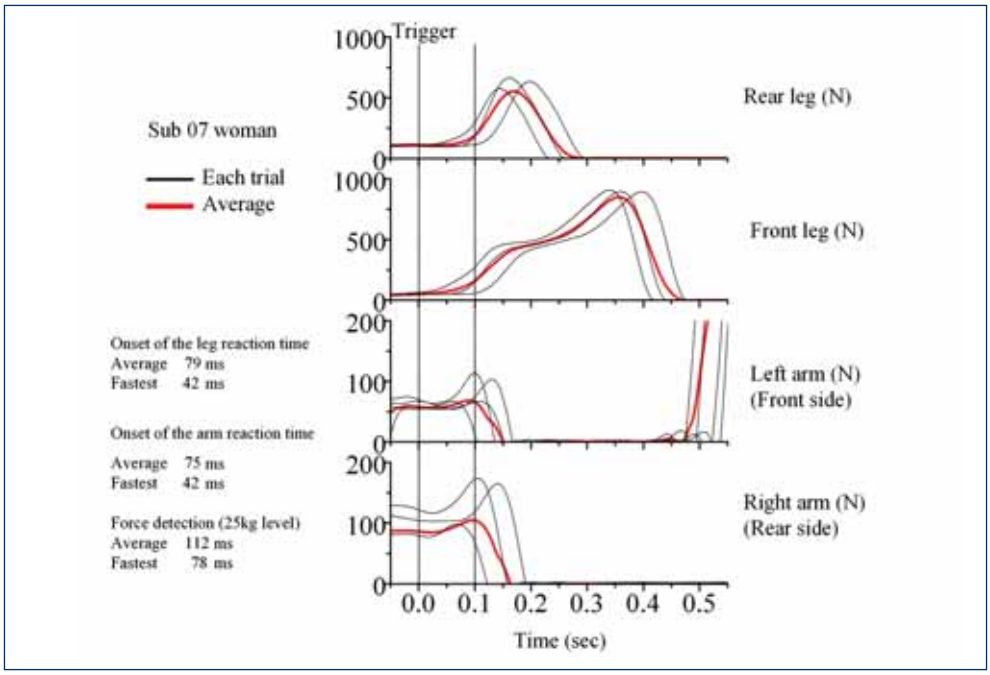

Figure 4.7: The time course data of the resultant forces for the arms and legs of subject 07

times less than 100 ms. These would have been considered as false starts according to the criteria used by the IAAF.

2. The time to the onset of muscle activation in the fastest start reaction condition was 60-80 ms.

As shown in Introduction, the neuromuscular response of the auditory reaction time during a sprint start can be less than 100 ms. Generally, after taking 3-6 ms for the start signal discharge to travel 1m to the ear of athlete, the sound stimulus can reach the motor cortex through the brain stem and auditory cortex in the time of 65 ms. Thereafter, the time from the motor cortex to the spinal cord and to the leg muscles can take 20-30 ms. Including the mechanical delay (5-10 ms), the total auditory reaction time takes approximately 100 ms (Figure 1).

However, as shown in a previous study (ROTHWELL & VALLS-SOLE, 2002), there is evidence that simple auditory reaction time of less than 100 ms can be achieved. For example, the startle reflex is thought to alter the information processing loops so that the auditory and motor cortices are bypassed and a prepared motor programme is released subcortically (BROWN et al., 2008). In this way, portions of the typical auditory motor pathway are bypassed, resulting in a decrease of reaction time.

The currently limit of 100 ms in the IAAF rules can be questioned for several reasons. Firstly, in addition to the present data, there are also other reports that demonstrate that values much below 100 ms are possible in good sprinters (PAIN & HIBBS 2007 and BROWN et al.,2008). Both of these studies are objective and very convincing. In fact PAIN & HIBBS (2007) went as far as suggesting that the auditory reaction time in the sprint start could be as low as 85 ms. Our experience supports this suggestion. Secondly, there is no question that the IAAF “rule” of

100 ms is based on something other than real neuromuscular-physiological evidence. This minimum reaction time limit does not take into consideration the size and gender differences among athletes. As the limit threshold is based more or less on the ability to produce the force (e.g. 25kg), the women are not able to reach this level as quickly as men (KOMI & KARLSSON, 1977).

The limit gives a signal that training cannot reduce the minimum reaction time of 100 ms at 25kg force level. Our Figure 1 is an attempt to describe schematically the sequence of delays in the neuromuscular system to auditory evoked reaction. There are important points in this scheme. First, the most uncertain time-delay takes place between brainstem and auditory cortex. It is likely that this delay, shown to last up to 50 ms, can most probably be interpreted to be under influence of training, for example. As this delay takes about half of the entire reaction time, any experimental data to verify its true value and possible adaptation to genetic as well as environmental conditions are more than welcome. Until this becomes possible we can only rely on objectively measured reaction time data that the total reaction time in the sprint start can be below 85 ms.

The sprint start reaction time as measured from the reaction forces on the blocks is very unnatural. The start action following the "stationary" set position is not just an action of the legs. It is a very comprehensive whole body movement. The examined muscles in the present study showed variable response times above the base line (Table 1), ranging, for example, from 59 ms (group average in the fast condition for the *tibialis anterior* muscle) to 91 ms (in the soleus muscle). The large standard deviations shown in Table 1 emphasise possibilities for even lower values. Knowing the relatively low value of electromechanical delay of 10-12 ms in humans (NICOLI & KOMI, 1996), the total reaction time for some muscles can be well below 100 ms. It is important to note that in the present study many of the athletes had acceptable motor times in the range of 75 to 80 ms and below for the *Vastus lateralis*, *Gastrocnemius* and *Soleus* muscles. All these muscles are responsible for extension movement of the legs against the starting block.

Conclusions

The following conclusions can be drawn from the present study:

1. Great individual differences can be observed in reaction times.

2. Reaction time in the sprint start can be lower than the 100 ms IAAF criteria. The values can in some cases be even below 80 ms (see the schematic presentation in Figure 5).

3. Reaction time in the sprint start is parameter dependent and has different values in different body parts. The values are usually lower in the arms than the legs.

4. As the reaction to the auditory stimulus in the sprint start involves activation of several muscles in the whole body and consequently activation and movement in the various body parts (e.g. neck, head, shoulder, arms, back, abdomen, hip, knee and ankle), the current application of the IAAF rule does not take this important "whole body involvement " into consideration.

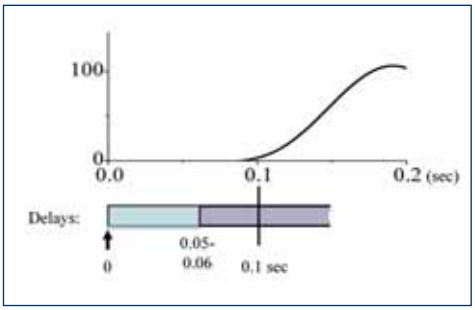

Figure 5: The schematics of the possibilities for the faster reaction (The horizontally shaded area shows the reaction times that have been observed experimentally in the sprint start.)

5. As the start of muscle activation is the first neuromuscular parameter to trigger the joint movement (and force production), the resulting kinematic changes should be considered as a key possibility for solving the complex problem of the current false start criteria.

Recommendations for the IAAF

1. As the present study gives essentially the same results as the ones published by independent researchers in Britain (PAIN & HIBBS, 2007) and Canada (BROWN et al., 2008), it is now recommended that the IAAF abandon the 100 ms minimum sprint reaction time level and its measurement with the current technical devices.

2. The level should be lowered to 80 or 85 ms, even if the block force production is still used as the parameter to set the level.

3. The IAAF should urgently examine possibilities for detecting the false start kinematically, so that the decision is based on the first visible movement regardless of the body part. This can be done with a system of high-speed cameras, which gives views of all the athletes on the start line. Modern technical possibilities are numerous in this regard, and the human eye can be considered as best to differentiate the first movement (shown by the high-speed camera) before the set minimum reaction time. Figure 6 is our suggestion for how the development project could be started. The figure does not show the cables to the monitor centre, in which one or two persons can make the decision a posteriori, but within 10-15 seconds after the gun firing.

4. Achieving point 3 above would lead to the situation where the rule could be changed so that no false starts are permitted.

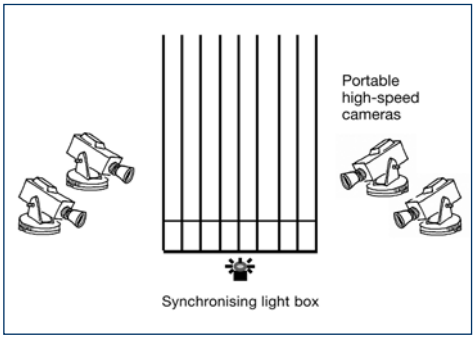

Figure 6: The schema of the proposed camera detection system

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