MAPPING OUT THE RESPONSE SEQUENCE OF THE SPRINT START

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Establishing the limits of sprint start response time (SSRT) requires the mapping of the muscular sequence of activation and mechanical response delays and was the aim of the current study. Sprint start performance of 15 sprinters was examined with kinematic, EMG, and block force data collected. A general muscle activation sequence was identified, with both deltoid muscles, the rear leg rectus femoris, and the rear leg tibialis anterior the first muscles to increase activation from the set position. With ankle dorsiflexion the initial motion during the block push, examining the period between tibialis anterior muscle onset and block force onset is critical for quantifying mechanical response delays. Estimates of this delay period were as low as 7 ms which has implications for our understanding of the minimum SSRT a sprinter can legally produce.

KEYWORDS: track and field, ankle joint, response time, EMG, force sensors.

INTRODUCTION: The sprint start response time (SSRT) is the time between the start signal and the first detectable response from starting block sensors and its detection presents an important biomechanical challenge. SSRT is affected by a sequence of neuro-physiological and non-neuro-physiological components and delays in the response can be mapped to an established sequence of events. The key delays in SSRT are: Signal processing time (SPT) which is the period from the start signal to the onset of muscle activation; Force development time (FDT) which constitutes the delay between muscle activation and the onset of muscle force. Currently, the World Athletics (WA) federation false start rule states that a sprinter is automatically disqualified when the official starter confirms that they registered a SSRT < 100 ms after the gun. However, research suggests the minimum SSRT may be shorter than 100 ms false start threshold (Komi et al., 2009) while other studies suggest the threshold be longer due to the limitations of existing technologies and the rules on false starts (Brosnan et al., 2017). Establishing the true limits on SSRT requires detailed mapping the muscular sequence of activation and quantifying delay periods during the sprint start. Examining the sequence of muscle activation and the mechanical response delays may contribute toward the debate surrounding the WA 100 ms false start threshold currently implemented in competition worldwide. Research from Komi et al. (2009) proposed FDT as an element in this delay sequence and estimated it to constitute approximately 5–10 ms of the response time process. Consequently, this study aims to map out the kinetic and muscular response sequence of the sprint start. While more proximal joints are larger contributors towards block impulse, the ankle joint is an important contributor and transfers more proximally generated force through the ankle onto the blocks (Brazil et al. 2017). As the major propulsive force in the sprint start is applied by the foot on the blocks it is important to consider delays in force application (i.e. SPT/FDT) in the ankle plantar flexors. Establishing the muscle sequence of activation and quantifying the duration of the SSRT delay components could contribute toward the WA 100 ms false start threshold debate and practically could be useful for determining the specificity of training exercises to the block phase.

METHODS: Following approval by the University Research Ethics committee, 15 sprinters (8 males, 7 females) volunteered for this study (Table 1). As the sprinters in this study participated across several events, their abilities in their specific sprint event were defined using the WA athletics scoring tables (Spiriev & Spiriev, 2017). Participant group abilities were classified in accordance with a framework (McKay et al., 2022), with the sprinter group comprised of highly trained/national level (*n* = 13) elite/international level (*n* = 1), and world-class (*n* = 1). Participants were excluded if they had a lower-leg injury in the previous six months.

Table 1. Demographics of the sprinters

Age (years)	Height (cm)	Mass (kg)	WA points (PB)	WA points (SB)	Experience (years)
23 ± 3	176.5 ± 10.5	72.6 ± 10.6	959.1 ± 90.8	952.8 ± 109.3	8.7 ± 2.7

Procedures: Sprint start testing took place in a biomechanics lab on a 9.6 m custom-built wooden platform, covered in a synthetic rubber surface. Sprinters wore their preferred non-reflective clothing and sprinting spikes and set the starting blocks to their preferred setup. After an individualised warm-up, each sprinter performed six maximal effort sprint starts with three minutes recovery between trials. Standard competition starting procedures were employed. Kinematic, EMG, SSRT, and block force data were collected during the sprint start testing.
Instrumentation: Kinematic data were collected using a 12-camera three-dimensional (3D) automated motion analysis system (Motion Analysis Corporation, CA, USA), recording at 250 Hz. Participants were equipped with 79 reflective markers attached to the head, upper body, and lower body, which includes 8 rigid four-marker clusters. EMG signals were acquired bilaterally from the anterior deltoid, rectus femoris, biceps femoris, gluteus maximus, lateral gastrocnemius, medial gastrocnemius, soleus, and tibialis anterior using a DELSYS Trigno EMG-system (Delsys, MA, USA). Forces exerted during the sprint start were quantified in millivolts using starting blocks instrumented with custom-made strain gauges measuring in the direction perpendicular to the block face. EMG signals and block force data were sampled at 2000 Hz using an external analog-to-digital converter (PowerLab 4/20; AD Instruments, Sydney, Australia), interfaced with a computer running LabChart 8 software.
Data analysis: The three trials with the shortest block clearance time were used for analysis. Marker labelling, tracking, and exporting of raw 3D marker coordinate data was performed in Cortex software (Motion Analysis Corporation, CA, USA). Following this, processing was performed in Visual 3D (C-Motion Inc, MD, USA). Raw marker coordinates were low-pass filtered (4^{th} order Butterworth) using a cut-off frequency of 12 Hz. Ankle joint angles were calculated as the distal segment coordinate system in reference to that of the proximal segment (i.e. ankle angle, foot in reference to the shank). Kinematic algorithms in Visual 3D were implemented to calculate ankle joint motion during the block phase (i.e. initial dorsiflexion and plantarflexion motion). EMG data were full-wave rectified, band-pass filtered between 10 and 400 Hz with a fourth-order zero-lag Butterworth filter and conditioned with the Teager-Kaiser energy operator prior to analysis. EMG data were filtered using a reverse-pass 4^{th} order Butterworth low-pass filter with a cut-off frequency of 50 Hz. All data treatments were performed in MATLAB (R2019a, MathWorks, MA, USA) using a custom-written script. SPT was calculated as the time difference between the start signal onset and the muscle EMG onset for each muscle for the front and the rear blocks. FDT of the tibialis anterior was calculated as the time difference between EMG onset and block force onset for each respective leg. The onset of EMG and block force was visually determined, with improved reliability of onset detection using visual rather than automatic detection methods (e.g. threshold-based methods) previously reported across fast, explosive and slow, maximal contractions (Crotty et al. 2021). Data are presented as group mean ± SD for muscle activation onsets and delay periods.

RESULTS AND DISCUSSION: FDT of the tibialis anterior was 19 ± 14 ms (range = 7-26 ms) for the rear block, and 24 ± 19 ms (range = 10-40 ms) for the front block. Since ankle dorsiflexion is the initial ankle movement during the block push phase (Figure 1,2), quantifying the delay between tibialis anterior muscle onset and block force onset (i.e. FDT tibialis anterior) is of interest when discussing the 100 ms threshold. This ankle mechanical delay period is variable between sprinters. However, estimates of this delay period constituting 5-10 ms appear valid (Komi et al. 2009), with 7 ms the lowest value observed in the current study. Lower values of FDT may be expected in sprinters of World-class level. SPT typically ranged from 0.106-0.213 s for the front block leg muscles and 0.083-0.192 s for the rear block leg muscles. These time to muscle activation onset after the signal are longer than observed in previous studies (Komi et al., 2009). Potentially, the lack of competitive block practice participants had due to COVID-19, or the lack of competitive environment during the sprint start trials (i.e. a competitor to run against) contributed towards this. Muscle activation patterns vary considerably between individuals however, a general muscle sequence of activation could be identified (Figure 1, 2). With the arm force reaction the first detectable biomechanical event in the start (Komi et al., 2009), it is unsurprising that the deltoid muscles (front block side: 0.054 ± 0.034 s, rear block side: 0.064 ± 0.029 s) were the first muscle group to increase activation from the set position. The rear leg rectus femoris (0.083 ± 0.058 s) and tibialis anterior (0.101 ± 0.042 s) are the first lower limb muscles to increase activation, followed by the front leg rectus femoris (0.106 ± 0.074 s) and tibialis anterior (0.135 ± 0.064 s). This aligns with knee extension and ankle dorsiflexion motions that generate initial propulsive block forces. While hip extension and hip extensor muscles are typically observed at the beginning of the sprint start (Coh et al., 2009), methodological issues meant that the gluteus maximus EMG was removed from this analysis. Following block force onset, the rear leg soleus (0.168 ± 0.053 s) is activated, alongside the rear leg biceps femoris (0.169 ± 0.055 s), aligning with the rear block plantarflexion and hip extension movement as the rear foot pushed away from the block face. The activation of the soleus muscle before either of the gastrocnemii muscles may relate to the influence of knee flexion in the “set” position shortening the biarticular gastrocnemii (Guissard & Duchateau, 1990; Schrodter et al. 2017). This finding is novel, with previous research showing no difference in plantar flexor muscle activation for the rear leg (Guissard & Duchateau, 1990). Following this, and similarly to the rear leg, the front leg soleus (0.186 ± 0.062 s) and medial gastrocnemius (0.186 ± 0.051 s), alongside the biceps femoris (0.183 ± 0.043 s) activate to initiate front block exit. The penultimate muscles to increase activation are the rear leg medial gastrocnemius (0.188 ± 0.037 s) and lateral gastrocnemius (0.192 ± 0.045 s), followed by the front leg lateral gastrocnemius (0.213 ± 0.060 s), coinciding with ankle plantarflexion through block exit to the initial portion of the flight phase, before dorsiflexion occurs in preparation for the first stance. Excluding the plantar flexor muscle onset patterns of the front and rear leg, the general sequence of muscle activation during the sprint start block phase is consistent with previous research (Coh et al., 2009; Guissard & Duchateau, 1990; Mero & Komi, 1990;). This highlights that there is a general consistent pattern of muscle activations across different samples of sprinters, however, that individual variations also exist potentially related to varying MTU lengths across studies and sprinters.

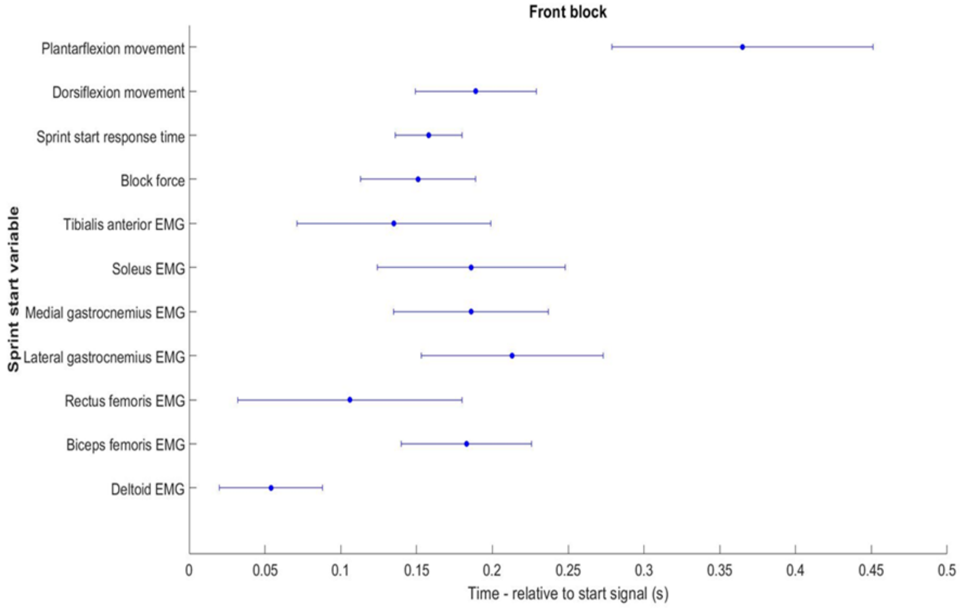

Figure 1 Sprint start muscle activity onsets, block force onsets, and ankle movement onset for the front block. Each line represents the group mean ± SD muscle activation onset time for that variable, relative to the start signal onset. The 0 on the x-axis represents the start signal onset.

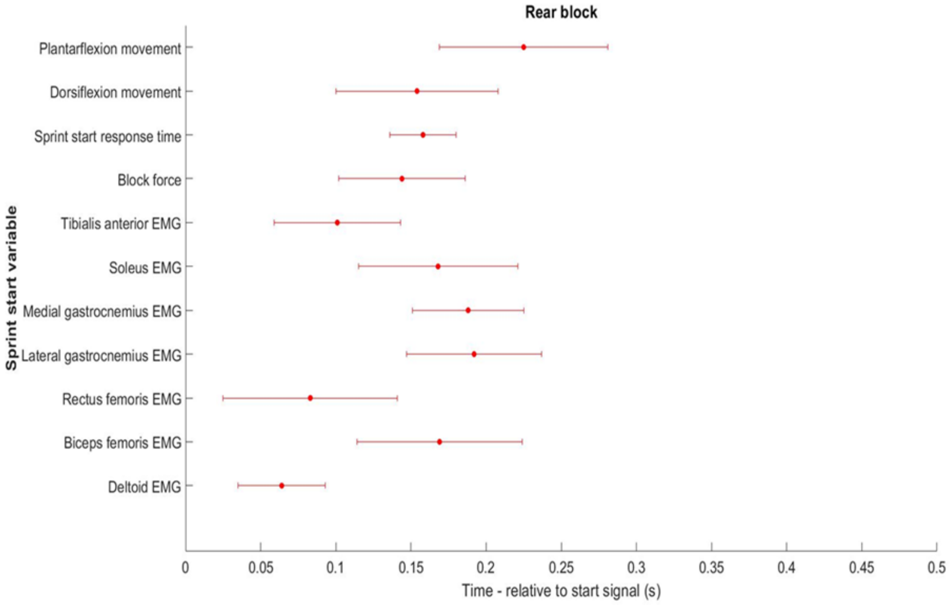

Figure 2 Sprint start muscle activity onsets, block force onsets, and ankle movement onset for the rear block. Each line represents the group mean ± SD muscle activation onset time for that variable, relative to the start signal onset. The 0 on the x-axis represents the start signal onset

CONCLUSION: Quantifying the delay between tibialis anterior muscle onset and block force onset (i.e. FDT) has implications for our understanding of the minimum SSRT a sprinter can legally produce, and was observed to be as low as 7 ms for the current sample of sprinters. The mapping of the muscular sequence of activations has practical implications, and whilst variable amongst sprinters, the general sequence identified, provides context for determining the specificity of training exercises to the block phase.

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