A METHOD COMPARISON OF BLOCK BASED ACCELEROMETERS AND FORCE SENSORS FOR DETERMINATION OF RESPONSE TIMES IN THE SPRINT START

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This study compares sprint start response times (RT) derived from load cells in the blocks with a RT from rail mounted accelerometer using methods similar to World Athletics (WA) approved start information systems (SIS). Seven national and international sprinters completed sprint trials that replicated race competition start procedures. Load cells were incorporated into starting blocks and the back block RT were analysed using: visual inspection (Visual RT), a 3SD threshold and CUSUM method, the rail accelerometer RT were analysed using a Visual RT and a 3SD Threshold method. On average the Rail Visual RT was detected 21 ms after the Visual Back Block RT and the Rail 3SD RT detected 27 ms after the Back Block 3SD RT. The results indicated the rail accelerometer detected RT after the back block load cells, highlighting the need for a review of SIS hardware and event detection software.

KEYWORDS: reaction time, sprint start, track and field.

INTRODUCTION: In major athletics championships, World Athletics (WA) require start information systems (SIS) for determining sprint athletes' response times (RT). Since 2010, any sprint athlete producing RT <100 ms after the start signal (Rule 162.6), will be disqualified under Rule 162.7 (IAAF, 2017) provided the start judge agrees with the SIS. RT measurements include the time for the athlete to react to the start signal including the mechanical delay of the SIS (Mero, Komi, & Gregor, 1992) however, current WA approved SIS may use different hardware (accelerometers or load cells) and different event detection methods. For example, the Swiss Timing SIS detect RT entirely from changes in force against the back block while the TimeTronics FalseStart III Pro uses an accelerometer system mounted on the block rail. Various studies (Brown, Kenwell, Maraj & Collins, 2008; Pain & Hibbs, 2007) demonstrated that event detection methods can also affect the RT determined for a sprint start, therefore questioning the validity and reliability of RT measurement when using current SIS to determine RT. The validity of the current 100 ms minimum RT rule has also been questioned (Brosnan, Hayes, & Harrison, 2017; Brown et al., 2008; Komi, Ishikawa, & Salmi, 2009; Lipps, Galecki, & Ashton-Miller, 2011; Mirshams Shahshahani, Lipps, Galecki, & Ashton-Miller, 2018; Pain & Hibbs, 2007). Analysis of RT data from major championships has shown that legal RT of <119 ms are unlikely using current SIS (Lipps et al., 2011; Brosnan et al., 2017). Willwacher, Feldker, Zohren, Herrmann, and Brüggemann (2013) found considerable differences between SIS and recommended the creation of a reference criterion for system developers. Overall, the literature indicates that delays in the detection of RT could be due to the hardware differences between systems and/or software-based methods used to detect RT. Subsequently, there is a need to examine the effects of event detection hardware and event detection algorithms on RT. This study aimed to compare RT's derived from a custom-built accelerometer mounted on the block rail, with RT from force sensors integrated in each block pad. The method comparison also examined the effects of three different event detection methods and algorithms (Visual, 3SD threshold & CUSUM) on RT.

METHODS: Seven national and international level sprinters (3 males, 4 females) volunteered for participation in this study. Participant age (mean ± SD) was 22.7 ± 3.0 years and training age was 9.3 ± 3.5 years. Participants' anthropometric characteristics are provided in Table 1. All participants were injury-free and testing procedures simulated training sessions and competitive races. All participants provided written consent and the study was approved by the local university research ethics committee.

Table 1: Anthropometric characteristics of participants

Variable	Male (n=3)		Female (n=4)	
	$\bar{x}$	SD	$\bar{x}$	SD
Mass (kg)	82.5	4.9	64.5	6.2
Height (cm)	184.8	5.3	168.8	8.3

Sprint Testing Protocol: Athletes performed individual race warm-ups including 3 warm-up block starts. Each athlete performed sprints from a block start over a minimum distance of 15 m. Trials were completed under race conditions and the starter followed race starting procedures, where SIS are absent, placing the athletes on their marks, holding them in set for a short period before initialising the trigger stimulus, with the starter judging if an athlete false started or not. All athletes completed 6 full starts with 3 minutes recovery between trials.
Instrumentation: The start signal was provided from a custom trigger box producing the acoustic stimulus less than one metre away from the athlete. The system consisted of Polanik starting blocks (PBS15-02-W, Polanik, Piotrków Trybunalski, Poland), which incorporated two load cells (F256EFR0KN, Novatech, Hastings, United Kingdom), one in each block pad and a surface mounted micro-machined silicone capacitive Accelerometer X-AXIS sensitivity (MMA2241KEG, Freescale Semiconductor, Inc. Austin TX, USA) located to the rear of the block rail and placed horizontally on it. Data collection occurred using two interconnected PowerLab systems 4/20 (ADInstruments, Sydney, Australia) with a sampling rate set at 2000 Hz.
Data Analysis: Raw data was collected from load cells in the blocks and a rail accelerometer. Three methods determined RT; firstly by visual inspection of graphs (Visual Rail RT & Visual Back Block RT) created with LabChart 8 software, determining the last point before a continuous incline in signal consistent with the initiation of a start. Secondly, by implementing a threshold method where 3×SD of the accelerometer or load cell signal variance was added to the mean before the stimulus, creating the Rail 3SD RT and Back Block 3SD RT. The Rail 3SD RT provided RT within 1 ms of TimeTronics FalseStart III Pro (Holmes, Hayes, & Harrison, 2018). Thirdly, by implementing a cumulative sum (CUSUM) algorithm to compare the rate of change in force in load cell signal in the back block using R (Back Block CUSUM RT). The three methods compared the effects of detection on RT, the initial reaction of the athlete Visual RT and CUSUM RT with the 3SD RT, some WA approved SIS implement pre-determined thresholds. No real-time event detection algorithms were used during testing. Pearson correlations and Limits of agreement (LoA) determined the relationships and inspected the level of agreement between the Visual Back Block RT with Visual Rail RT, Back Block CUSUM with Back Block Visual RT and Back Block 3SD RT with Rail 3SD RT. Four trials were excluded; two of these were deemed faulty starts by the athletes and the Back Block 3SD threshold was too sensitive for two trials. No athlete had more than one trial excluded. All statistical analyses were completed in R 3.6.2.

RESULTS: The mean, minimum and maximum scores are presented for Visual Rail RT, Visual Back Block RT, Rail 3SD RT, Back Block 3SD RT and Back Block CUSUM RT in Table 2.

Table 2: Summary of RT Methods

Detection Method of RT	$\bar{x}$ RT (s)	SD (s)	Min RT (s)	Max RT (s)
Visual Rail RT	0.148	0.027	0.086	0.208
Visual Back Block RT	0.127	0.026	0.075	0.182
Rail 3SD RT	0.157	0.025	0.102	0.213
Back Block 3SD RT	0.130	0.030	0.078	0.196
Back Block CUSUM RT	0.124	0.025	0.072	0.179

Figure 1 provides an example of a single-trial. The results showed that Back Block Visual RT and 3SD RT were detected before the Rail Visual RT and 3SD RT in 37 of the 38 trials.

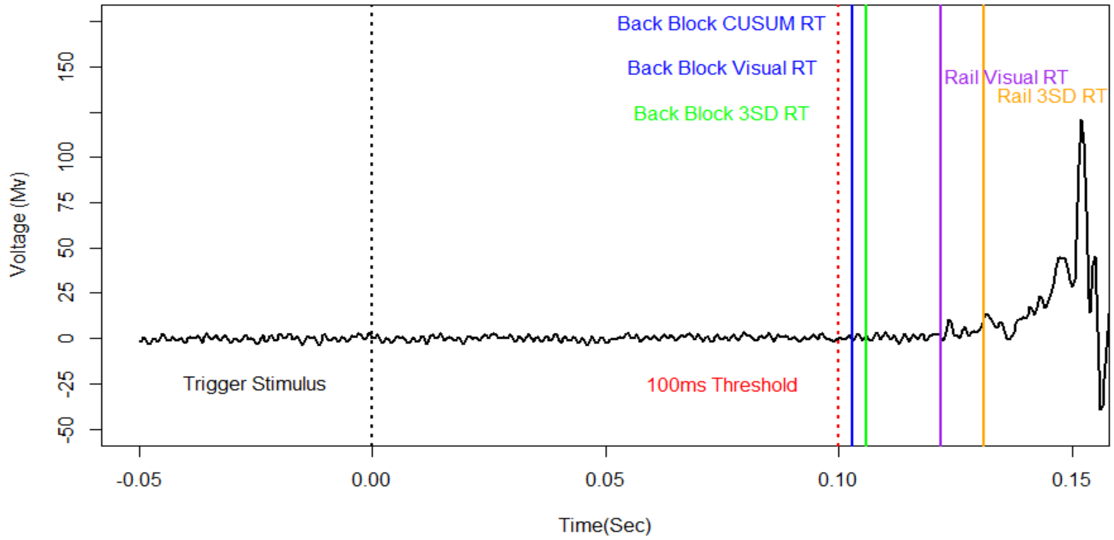

Figure 1: Demonstrating rail accelerometer data and additional lines specifying the Trigger Stimulus (black), 100 ms Threshold (red), Back Block CUSUM RT and Back Block Visual RT (blue), Back Block 3SD RT (green), Rail Visual RT (purple) and Rail 3SD RT (orange), for a single trial.

Table 3 provides Pearson correlations indicating strong relationships between Back Block Visual RT and Rail Visual RT and the Back Block CUSUM RT and Back Block Visual RT and a moderate relationship for the Back Block 3SD RT and Rail 3SD RT respectively. Mean differences between Back Block Visual RT and Rail Visual RT of 20 ms and Back Block 3SD versus RT Rail 3SD RT of 28 ms indicated a bias from the hardware.

Table 3: Comparison of RT Methods

Methods Compared	Mean difference (s)	Lower Limits of Agreement	Upper Limits of Agreement	Pearson Correlation
Back Block Visual RT – Rail Visual RT	-0.020	-0.046	0.006	0.88 ***
Back Block CUSUM RT - Back Block Visual RT	-0.003	-0.018	0.011	0.96 ***
Back Block 3SD RT – Rail 3SD RT	-0.028	-0.074	0.016	0.68 ***

******* p<0.001

DISCUSSION: In this study, the LoA and correlation analysis showed strong to moderate correlations but substantial systematic bias when comparing RT across different hardware types using the same detection methods. The Back Block RT vs Rail RT detected mean Rail Visual RT 20 ms after the Back Block Visual RT and the mean Rail 3SD RT detected RT 28 ms after the Back Block 3SD RT. These results indicate that rail accelerometers would detect later RT than load cells on blocks, therefore WA should reconsider the appropriateness of using accelerometer-based systems. The correlation (*r* = 0.96; p < 0.001) and LoA (bias = 3 ms) results for Back Block CUSUM RT vs Visual RT showed good comparability between the visual and CUSUM detection methods, indicating that both methods detected the initiation of the start (i.e., increase in force), which is conceptually similar to methods used by (Brown et al., 2008; Pain & Hibbs,

2007), who detected many legal RT <100 ms. In this study, several athletes produced RT <100 ms for Back Block CUSUM RT and Back Block Visual RT which could be considered as valid and legal RT if an accelerometer-based system or current SIS were used. These results indicate that RT values detected by WA approved SIS systems may be erroneously inflated by the threshold-based detection algorithms used in these systems. Consequently, WA should re-examine the current minimum auditory time threshold of 100 ms with existing systems, which was previously considered to be 120 ms until 1990 (Pain & Hibbs, 2007). Athletes producing genuine RT <119 ms when using WA approved SIS are unlikely to be valid RT (Lipps et al., 2011; Brosnan et al., 2017). Implementation of thresholds by gender should be standardised, females would have required a 22% threshold reduction to produce similar RT to males (Lipps et al., 2011).
Overall, the results of this study provide further evidence questioning the validity of the hardware and event detection software in existing WA approved systems. Brosnan et al. (2017) suggested replacing threshold-based methods with an algorithm to detect initial block rise using algorithms similar to the Visual RT and CUSUM RT implemented in this study. Willwacher et al. (2013) stated that reference criteria should be established for approved SIS manufacturers to optimise SIS. This study found the rail accelerometer detected RT later than force sensors consistently consequently, emphasising that the rail values are suspect for determination of the reaction and therefore results indicate force sensors provide a superior method for detecting the initiation of force production and determination of RT, recommended for use in SIS for detection an athletes initial reaction. The CUSUM and visual event detection methods appear to be more effective than the 3SD methods in detecting the initial response. However, from these two options, the CUSUM algorithm has potential for real-time implementation to detect the initiation of the start and would provide a fairer method compared to a pre-determined level or variance threshold method.

CONCLUSION: There is an urgent need to review the detection methods of SIS and re-evaluate the current 100 ms threshold approved for use with both accelerometer and force sensor based SIS. This study found that both the detection algorithm and hardware influenced RT. The rail accelerometer detected RT later than the back block force changes in 37/38 trials with a mean difference of 20 ms for the Visual RT method comparison and 28 ms for the 3SD RT. A real-time version of the CUSUM algorithm could replace pre-determined threshold methods and provide a fairer determination of an athlete's initial reaction and RT in competition.

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