Bias in estimated short sprint profiles using timing gates due to the flying start: simulation study and proposed solutions

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Short sprints have been modeled using the mono-exponential equation that involves two parameters: (1) maximum sprinting speed (MSS) and (2) relative acceleration (TAU), most often performed using the timing gates. In this study, this model is termed the *No correction* model. Unfortunately, due to the often utilized flying start, a bias is introduced when estimating parameters. In this paper, (1) two additional models are proposed (*Estimated TC* and *Estimated FD*) that aim to correct this bias, and (2) a theoretical simulation study that provides model performances in estimating parameters is provided. In conclusion, both *Estimated TC* and *Estimated FD* models provided more precise parameter estimates, but surprisingly, the *No correction* model provided higher sensitivity for specific parameter changes.

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Introduction

Sprint speed is one of the most distinctive and admired physical characteristics in sports. In most team sports (e.g., soccer, field hockey, handball, etc.), short sprints are defined as maximal sprinting from a standstill across a distance that does not result in deceleration at the finish. Peak anaerobic power is reached during the first few seconds (<5 *s*) of maximal efforts (Mangine et al. 2014)); however, the capacity to attain maximal sprint speed is athlete- and sport-specific. For instance, track and field sprinters are trained to achieve maximal speed later in a race (i.e., 50-60 *m*) (Ward-Smith 2001), whereas team sport athletes have sport-specific attributes and reach maximal speed much earlier (i.e., 30-40 *m*) (Brown et al. 2004).

The evaluation of short sprint performance is frequently included in a battery of fitness tests for various sports, regardless of the kinematic differences between athletes.

The use of force plates is regarded as the gold standard for analyzing the mechanical features of sprinting; nevertheless collecting the profile of a whole sprint presents practical and cost problems (Samozino et al. 2016; Morin et al. 2019). Radar and laser technology are frequently utilized laboratory-grade methods (Buchheit et al. 2014; Jiménez-Reyes et al. 2018; Marcote-Pequeño et al. 2019; Edwards et al. 2020) that are typically unavailable to sports practitioners. Timing gates are unquestionably the most prevalent method available for evaluating sprint performance. Multiple gates are frequently placed at different distances to capture split times (e.g., 10, 20, 30, and 40 m), which can now be incorporated into the method for determining sprint mechanical properties (Samozino et al. 2016; Morin et al. 2019). Practitioners can utilize the outcomes to explain individual differences, quantify the effects of training interventions, and gain a better knowledge of the limiting variables of performance, which is an advantage of this method.

Mathematical model

The mono-exponential Equation **??** has been used to model short sprints. It was first proposed by Furusawa et al. (1927) and made more popular by Clark et al. (2017) and Samozino et al. (2016). Equation **??** is the function for instantaneous horizontal velocity v given time t and two model parameters.

$$v(t) = MSS \times (1 - e^{-\frac{t}{TAU}}) \tag{1}$$

Maximum sprinting speed (MSS; expressed in ms^{-1}) and *relative acceleration* (TAU; expressed in s) are the parameters of Equation **??**. TAU represents the ratio of MSS to initial acceleration (MAC; *maximal acceleration*, expressed in ms^{-2}) (Equation **??**). Note that TAU, given Equation **??**, is the time required to reach a velocity equal to 63.2% of MSS.

$$MAC = \frac{MSS}{TAU} \tag{2}$$

Although TAU is utilized in the equations and afterward estimated, it is preferable to use and report MAC because it is simpler to understand, especially for practitioners and coaches.

By deriving Equation **??**, Equation **??** is obtained for horizontal acceleration.

$$a(t) = \frac{MSS}{TAU} \times e^{-\frac{t}{TAU}} \tag{3}$$

By integrating Equation **??**, equation for distance covered (Equation **??**) is obtained.

Table 1: Sample split times measured during 40 m sprint performance using timing gates positioned at 5, 10, 20, 30, and 40 m

Distance (m)	Split time (s)
5	1.34
10	2.06
20	3.29
30	4.44
40	5.56

$$d(t) = MSS \times (t + TAU \times e^{-\frac{t}{TAU}}) - MSS \times TAU \tag{4}$$

Model parameters estimation using timing gates split times

Table **??** contains sample split times measured during 40 m sprint performance using timing gates positioned at 5, 10, 20, 30, and 40 m.

To estimate model parameters using split times, distance is a *predictor* and time is the *outcome* variable; hence, Equation **??** takes the form of Equation **??**).

$$t(d) = TAU \times W(-e^{\frac{-d}{MSS \times TAU}} - 1) + \frac{d}{MSS} + TAU \tag{5}$$

W in Equation **??** represents *Lambert's W* function (Goerg 2022). Equation **??**), in which time is the predictor and distance is the outcome variable, is commonly employed in research (Morin 2017; Morin and Samozino 2019; Stenroth and Vartiainen 2020). This method should be avoided since reversing the predictor, and outcome variables in a regression model may create biased estimated parameters (Motulsky 2018, p. 341). This bias may not be practically significant for profiling short sprints, but it is a statistically flawed practice and should be avoided. It is thus preferable to utilize statistically correct Equation **??**) to estimate model MSS and TAU.

Estimating MSS and TAU parameters using Equation **??** as the model definition is performed using *non-linear least squares regression*. To the best of my knowledge, scientist, researchers, and coaches have been performing short sprints modeling using the built-in solver function of Microsoft Excel (Microsoft Corporation, Redmond, Washington, United States) (Samozino et al. 2016; Clark et al. 2017; Morin 2017; Morin and Samozino 2019; Morin et al. 2019; Stenroth et al. 2020; Stenroth and Vartiainen 2020). These, and additional functionalities, have been recently implemented in the open-source **{shorts}** package (Vescovi and Jovanović 2021; Jovanović 2022; Jovanović and Vescovi 2022) for R-language (R Core Team 2022), which utilizes the `nlsLM()` function from the **{minpack.lm}** package (Elzhov et al. 2022). Compared to the built-in solver function of Microsoft Excel, the **{shorts}** package represents a more powerful, flexible, transparent, and reproducible environment for modeling short sprints. It is used in this study to estimate model parameters.

Using the split times from Table **??**, estimated MSS, TAU, and MAC parameters equal to 9.02 ms^{-1}, 1.14 s, and 7.94 ms^{-2}, respectively. *Maximal relative power* (PMAX; expressed in W/kg) is an additional parameter often estimated and reported (Samozino et al. 2016; Morin et al. 2019). PMAX is calculated using Equation **??**. This method of PMAX estimation disregards the air resistance and thus represents *net* or relative *propulsive* power. Calculated PMAX using estimated MSS and MAC parameters equal to 17.91 W/kg.

$$PMAX = \frac{MSS \times MAC}{4} \tag{6}$$

Problems with parameters estimation using split times due to flying start and reaction time

To ensure accurate short sprint parameter estimates, the initial force production must be synced with start time, often reffed to as "first movement" triggering (Haugen et al. 2012; Haugen and Buchheit 2016; Samozino et al. 2016; Haugen et al. 2019; Haugen, Breitschädel, and Seiler 2020; Haugen, Breitschädel, and Samozino 2020). This represents a challenge when collecting sprint data using timing gates and can substantially impact estimated parameters.

To demonstrate this impact, imagine three hypothetical twin brothers, Mike, Phil, and John, with the same short sprint characteristics: MSS equal to 9 ms^{-1}, TAU equal to 1.125 s, MAC equal to 8 ms^{-2}, and PMAX equal to 18 W/kg (these represent *true* short sprint parameters). They all perform a 40 m sprint from a standing start using timing gates positioned at 5, 10, 20, 30, and 40 m. For Mike and Phil, the timing system is activated by the initial timing gate (i.e., when they cross the beam) at the start of the sprint (i.e., $d = 0$ m). For John, the timing system is activated after the gunfire.

Mike represents the *theoretical model*, in which it is assumed that the initial force production and the timing initiation are perfectly synchronized. Mike's split have already been enlisted in Table **??**.

On the other hand, Phil decides to move slightly behind the initial timing gate (i.e., for 0.5 m) and use body rocking to initiate the sprint start. In other words, Phil uses a *flying start*, a common scenario when testing field sports athletes. From a measurement perspective, flying start distance is often recommended to avoid premature triggering of the timing system by lifted knees or swinging arms (Altmann et al. 2015; Haugen and Buchheit 2016; Altmann et al. 2017; Altmann et al. 2018; Haugen, Breitschädel, and Samozino 2020). Flying start can also result from body rocking during the standing start. Clearly, any flying start with a difference between the initial force production and the start time can lead to skewed parameters and predictions. Since it is hard to get faster at a sprint, inconsistent starts can hide the effects of the training intervention.