



**The effects of the false start disqualification rules on the reaction times of elite sprinters**

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THE EFFECTS OF THE FALSE START  
DISQUALIFICATION RULES ON THE REACTION TIMES  
OF ELITE SPRINTERS

Abstract

The 100 ms ruling for false start disqualification at athletic competitions governed by the International Association of Athletics Federations has been in force since the early 1990's. Throughout this period, significant changes have been made to the rules governing the disqualification of athletes from sprint events incorporating starts from blocks. This study analysed all available World and European Championship reaction time data from 1999 to 2014 to examine the effect of rule changes on competition reaction times at major championships. The exponentially modified Gaussian distribution was used to model the reaction times and make comparisons relative to sex, ruling periods and competition rounds. Revised reaction time thresholds of 115 ms and 119 ms were calculated for men and women respectively, indicating that the current 100 ms rule could result in some false starts not being detected in competitive athletics. The study proposes that when using existing International Association of Athletics Federations approved systems, the false start detection threshold should be increased and that men and women athletes should have different thresholds due to the substantial evidence of a sex difference in reaction times in elite athletes.

**Keywords:** sprint start; athletics; exponentially modified Gaussian distribution; auditory performance.

Introduction

The reaction time (RT) of elite 100 m sprinters has been identified as a benchmark against which to gauge the absolute limits of human auditory performance (Lipps, Galecki et al., 2011). A RT in the context of this paper is similar to that used in the seminal paper by Mero and Komi (1990) defined as the complete response time of an athlete which includes both the pre-motor time and

motor time of the sprint start. Accurate identification of the RT period after the start signal in sprint starts especially at major championships is vital for the fair and impartial refereeing of competitive athletics.

The International Association of Athletics Federations (IAAF) rule 161.2 stipulates that a false start occurs when a sprinter registers a RT less than 100 ms (International Association of Athletics Federations, 2015). Before January 2004, a RT of less than 100 ms (i.e. a false start) resulted in a warning on a competitor and the competitor was disqualified for two false starts in a race. From January 2004, a false start by any competitor placed all the athletes in the race on a first warning. Subsequently, any sprinter registering a false start would be automatically disqualified regardless of whether (s)he was the original offender. To eradicate gamesmanship (Athletics Australia, 2009), the IAAF made further significant changes to the false start disqualification rule in January 2010. Under the revised “No False Start” rule, no warnings are issued and a competitor who false starts is automatically disqualified and removed from the race.

The 100 ms latency period used to detect a false start is measured as the time taken by an athlete to produce a predefined force or acceleration threshold on the starting blocks. Lipps, Galecki et al. (2011) noted that the IAAF justification for this 100 ms threshold is based on a considerably dated study involving eight non-elite Finnish male sprinters (Mero and Komi, 1990). Pain and Hibbs (2007) suggested that genuine RTs of 85 ms are possible and Brown, Kenwell et al. (2008) presented similar results observing 21% of recorded RTs being faster than the 100 ms temporal threshold. While such RTs are possible, the recording

systems used in both studies measured the time to the first change in force on the blocks produced by the athlete rather than the time taken to produce a predefined force. A revision of the false start detection threshold was proposed by Komi, Ishikawa et al. (2009), based on a study of sprint starts on four male and three female, Finnish national-level sprinters. While this study raised questions over the validity of the current 100 ms rule, it was weakened by having a small sample of participants with limited major championship status.

Previous studies have provided empirical evidence of a sex difference in the strength of elite athletes (Lipps, Galecki et al., 2011) and of the general population (Der and Deary, 2006), but IAAF rule 161.2 continues to use a single RT threshold of 100 ms. Given the physiological differences in strength in men and women, it is possible that a sex difference in RTs could require that the rules for men's and women's events should be determined independently.

Clearly, a re-evaluation of the 100 ms threshold is required using analysis of data recorded using IAAF approved starting technologies and relevant data from international competitions. Collet (1999) studied the RTs of elite competitors between 1987 and 1997, while Tønnessen, Haugen et al. (2013) carried out a similar analysis for events between 2003 and 2009. While both of these studies add significantly to the sprint start RT literature the data utilised only spans a single ruling period. Haugen, Shalfawi et al. (2013) carried out a study on elite athletes over the period 1997 – 2011, but focused solely on the 100 m sprint across the three ruling periods of interest. They suggested a 20% increase in RTs over a 15 year period, but did not provide a full analysis of the differences across

ruling periods due to the lack of data for the third ruling period. All of the previous studies have been based on restricted sample sizes and many do not include data from athletes of international major championship status. Appropriate statistical analysis and modelling of a large sample of male and female athlete RTs at major international championships could be used to derive an appropriate temporal threshold for sprint start RTs in competitive athletics. Consequently, the primary aim of this study was to determine whether IAAF rule changes have influenced the competition RTs of elite sprinters in major international championships by statistically modelling the historical RT data and determining potential differences across ruling periods, sex and round of competition. The secondary aim was to establish whether the data collected across multiple major championship competitions could be combined and used to revise the IAAF 100 ms reaction time for male and female sprinters accordingly using a statistical modelling approach.

## Methods

### *Data Acquisition*

The collection and analysis of the data utilised in this study received research ethics approval from the University of Limerick Education and Health Sciences Research Ethics committee (2013\_06\_07\_EHS). RT data was collated from the IAAF results (<http://www.iaaf.org/results>) and the European Athletics websites (<http://www.european-athletics.org/results/>) and includes complete Championship event data for the 60 m and 60 m hurdles indoor championships, the 100 m, 110 m hurdles and the 200 m outdoor championships over the period from 1999 to 2014 inclusive. Events over distances greater than 200 m were

excluded since the RT has less influence on the performance and therefore would not provide valid information on the quickest possible RT of an elite athlete. The data contained race RTs for 1303 and 1007 men and women, respectively, with a total of 4560 and 3999 RT records for performances of men and women respectively. While the available data contained additional information on the finish time, wind speed and name of the sprinter, the only variables of interest in this study were the RT of the sprinter, the year of the event and the round of the competition. Based on an extensive literature search, this study constitutes the largest exploration of RTs of elite sprinters to date and far exceeds the work of Mero and Komi (1990) which is proposed as the basis for the current 100 ms threshold (Lipps, Galecki et al., 2011).

***Exploratory Analysis***

Descriptive statistics for the centre and variability of RTs relative to sex and ruling periods were calculated. Box-and-whiskers plots provide visualisation of the RTs of men and women across ruling periods. The exploratory analysis also examined the number of false starts recorded in each ruling period. An analysis was also conducted to identify if the use of OMEGA and SEIKO starting technologies at European and World Championships impacted the recorded RTs of athletes.

***Statistical Modelling***

The exponentially modified Gaussian distribution (EMGD) has been widely used to model RTs (Dawson, 1988). The EMGD is a convolution of an exponential

distribution, controlling the tail of the distribution, and a Gaussian distribution to represent the group of quickest reactions. Its probability density function is:

$$f(RT|\mu, \sigma, \tau) = \frac{1}{\tau} \exp\left\{\frac{\mu}{\tau} + \frac{\sigma^2}{2\tau^2} - \frac{RT}{\tau}\right\} \Phi\left(\frac{RT - \mu - \frac{\sigma^2}{\tau}}{\sigma}\right),$$

where,  $\mu$  and  $\sigma$  represent the mean and standard deviation of the Gaussian component and  $\tau$  is the rate parameter of the exponential distribution, while  $\Phi(t)$  is the cumulative standard normal distribution function evaluated at  $t$ . The parameters are constrained such that  $\min(RT) \leq \mu \leq \max(RT)$ ,  $0 \leq \sigma \leq \text{range}(RT)$  and  $0 \leq \tau \leq \text{range}(RT)$ . If the RTs follow an EMGD with the above parameters its measure of location and scale can be represented as  $\mathbb{E}(X) = \mu + \tau$  and  $\text{Var}(X) = \sigma^2 + \tau^2$ , respectively.

### ***Estimation***

The parameters for the EMGD were estimated using the maximum likelihood approach provided in the retimes package (Massidda, 2013) based in the R statistical computing environment (R Core Team, 2015). The maximum likelihood estimates of the parameters for the EMGD are described in detail in Silver, Ritchie et al. (2009).

### ***Goodness-of-fit Statistics***

Pearson's Chi-Squared goodness-of-fit was used to evaluate if the observed RT data came from an underlying EMGD. The null hypothesis assumed that the data fitted the distribution well, while the alternative assumed that the distribution was not a true reflection of the observed data, more detail of this goodness-of-fit test can be found in Greenwood and Nikulin (1996). For this study a significance level of  $\alpha = 0.05$  was used, with  $r - p - 1$  degrees of freedom, where  $r$  is the number of quantiles at which the fit is compared, 10 is

used in all calculations in this study, and  $p$  is the number of estimated parameters which is 3 for all cases when using the EMGD. The critical value is taken from the Chi-squared tables with 6 degrees of freedom at a significance level of 0.05 which corresponds to a critical value of 12.592.

**Comparison across ruling periods and rounds**

To compare differences across ruling periods and rounds, a simple probabilistic approach was taken. The probability of a RT above a given threshold,  $T$ , being observed can be expressed as  $\Pr(RT \geq T) = 1 - \Pr(RT < T)$ . In turn, the  $\Pr(RT < T) = F(T)$  where  $F(T)$  is the cumulative distribution function (CDF) of the EMGD evaluated at  $T$ . The CDF is formulated by integrating the probability density function shown above, resulting in the CDF for the EMGD being:

$$F(T) = -\exp\left(\frac{-T}{\tau} + \frac{\mu}{\tau} + \frac{\sigma^2}{2\tau^2}\right)\Phi\left(\frac{T - \mu - \frac{\sigma^2}{\tau}}{\sigma}\right) + \Phi\left(\frac{T - \mu}{\sigma}\right),$$

where,  $T$  is the threshold of interest,  $\mu$ ,  $\sigma$  and  $\tau$  are the parameters of the EMGD defined earlier and  $\Phi$  is again the CDF of the standard normal distribution. In addition the probability of superiority is used to compare populations of interest. The statistic returns a probability that a randomly chosen member of the “upper” population lies above the median of the “lower” population; a value of greater than 50% indicates a difference in the two populations.

**Revision of the False Start Detection Threshold**

For men and women, an EMGD was estimated to fit the sex specific RTs across all ruling periods. The CDF of the EMGD presented earlier was utilised to find



the threshold ( $T$ ) which 99% of the observed RTs lay above. The identified threshold is proposed as an effective method to determine the true minimum RT by an elite athlete using the current technology approved by the IAAF.

## Results

Men's events reported a median value of 156 ms and 159 ms for World and European Championships respectively, while women's events reported medians of 161 ms and 164 ms respectively. Table 1 provides descriptive statistics for the RTs of elite sprinters relative to rule change periods set down by the IAAF for men and women. The median and a 95% coverage interval are reported as a positive skew was observed in the RTs. The rows of the table represent the combination of ruling period and sex. The columns provide the number of observations, the median, a 95% coverage interval and the number of false starts recorded in the period.

\*\*\*\*Table 1 near here\*\*\*\*

Box-and-whisker plots for the RTs by ruling period are presented in Figure 1. The left panel represents the men while the women are presented in the right panel. The  $x$ -axis for both panels corresponds to the three ruling periods with the commonly scaled  $y$ -axis representing RTs in milliseconds. The horizontal dashed line at 100 ms denotes the current disqualification limit – while RTs are recorded below 100 ms they correspond to false starts which are not a true reflection of the shortest valid RTs in elite athletics. The circled numbers below the threshold line provide the number of disqualifications due to false starts relative to sex and ruling period.

\*\*\*\*Figure 1 near here\*\*\*\*

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The results of fitting the EMGD for men and women in each ruling period are provided in Table 2 and Figure 2. These also compare the distributional properties of RTs from first round events and finals, since races of greater importance may encourage athletes to take risks and anticipate the start signal. The parameters column presented in Table 2 provides the best estimates of the EMGD parameters given the data from the ruling period and sex, the properties column shows the location and scale of the distribution, while the final two columns provide a measure of goodness-of-fit of the estimated EMGD to the observed data with the corresponding p-value for the result of the test.

\*\*\*\*Table 2 near here\*\*\*\*

The estimated distributions for ruling periods, first round and finals by sex are shown in Figure 2. Panels A and B show the fit for each of the three ruling periods, the dotted line is the fit for the 1999-2003 ruling period, the dashed line is the estimated distribution for the 2004-2009 period, while the immediate disqualification ruling distribution is the solid line. Panel C and D provide a visualisation of the estimated EMGD fits for the first round heats, (dashed line), and finals, (solid line), for both men and women.

\*\*\*\*Figure 2 near here\*\*\*\*

The probabilistic approach for identifying a difference across ruling periods and rounds is determined by calculating the probability of observing a RT greater than 120 ms. For ruling periods the respective probabilities are 0.95, 0.98 and 1.00 for men and 0.97, 0.99 and 1.00 for women. The probabilities of observing RTs above 120 ms in first rounds are 0.98 and 0.99 and in finals are 0.98 and 0.97 for men and women respectively. Table 3 provides the probability of

superiority for pairs of populations and in all cases the probability was above 50% indicating that the compared distributions differed.

\*\*\*\*Table 3 near here\*\*\*\*

The revision of the false start disqualification limit calculated from the historical data relevant to sex resulted in both thresholds exceeding the current 100 ms limit. Men's event data proposed a revised limit of 115 ms while the women's event data suggested a limit of 119 ms.

## Discussion

The median values for RTs at World and European Championships filtered by sex, showed absolute differences of 3 ms for men's and women's events. This small difference shows that the different measurement technologies used at World and European Championships was not an important factor in this study and supports the decision to analyse pooled data from European and World Championships. The 95% coverage interval of RTs of the entire data shows a lower bound of 122 ms, 22 ms above the threshold set down by the IAAF. For a 100 m sprinter 22 ms can be a significant advantage. For example, in the 2012 Olympic Games in London the winning margin between the first and second athletes in the women's 100 m event was only 30 ms, and at a typical velocity of 10 m/s, this difference represents a 30 cm advantage. If the 100 ms threshold fails to detect a false start, it is possible that an athlete could anticipate the start without disqualification and this could alter the results of an event.

## *Ruling Periods*

The median and 95% coverage intervals for each ruling period shown in Table 1 indicates shifts in the distributions of the RTs of athletes in periods after a rule

change by approximately 5 ms for men and 7.5 ms for women. While the shift in RTs of sprinters after the rule change in 2004 is not particularly noticeable in Figure 1, a noticeable shift does appear after the rule change in January 2010, this is consistent with the results shown in Haugen, Shalfawi et al. (2013) and in Tønnessen, Haugen et al. (2013) which was restricted to 100 m sprinters. This is also in line with the probability of superiority shown in Table 3 with men and women showing a greater probability of superiority after the second rule change. The comparison between the earliest and latest ruling periods is of interest with 72.1% and 74.5% probability of superiority for men and women respectively, indicating that significant shifts in distributions has occurred between these ruling periods. Figure 2 panels A and B, suggest that for ruling periods, the EMGD of men and women has an increasing trend over time. It is evident in both sexes that a shift over time has occurred with a significant shift in the distribution density after the automatic disqualification ruling in January 2010. The sex difference can also be identified as panels A and B of Figure 2 are on the same scale, with the densities for women being shifted further to the right. The probability of observing a RT greater than 120 ms increases for men and women relative to the ruling periods. The probability of observations greater than 120 ms following the introduction of the automatic disqualification rule in 2010 is 1, irrespective of sex. This suggests that the minimum observed RT of athletes recorded using the current IAAF approved technology and rules is greater than 120 ms, some 20 ms above the enforced threshold.

**Competition Rounds**

A comparison of the RTs in first round heats and finals is shown in panels C and D of Figure 2. A reduction of the RTs in finals suggests that athletes are more

likely to anticipate the start signal when the race is more important, this is consistent with the observed shift in RTs by competition round shown in Tønnessen, Haugen et al. (2013) which examined only the 2003 – 2009 ruling period. A shift to the left indicating a decrease in RT is evident in both cases, suggesting that athletes are more likely to take risks in finals than in first round heats. This difference is evident in the Table 3 where the probabilities of superiority for men and women are 0.656 and 0.638 respectively, therefore regardless of sex, RTs in finals are typically quicker than in first rounds. A sex difference is evident by the comparison of the plots with the RT distribution for women shifted further to the right. The probabilistic approach for the difference between RTs greater than 120 ms in first rounds and finals shows a relative difference for women, this may be due to the fact that men are willing to take a risk at all levels whereas women require a significant incentive to take that risk, as discussed in Whitley, Nelson et al. (1999).

### ***Sex Difference***

The assertion by Lipps, Galecki et al. (2011) of a sex difference in RTs is evident throughout this study and can be further explained by the strength and rate of force development differences between men and women, allowing men to produce the required force to reach the false start threshold quicker. A difference in RT relevant to sex was observed across both ruling periods and competition rounds. This prominent sex difference supports the case for independent false start detection limits for men and women as suggested by Lipps, Galecki et al. (2011). In addition this evident sex difference is consistent with the suggestion of Lipps, Galecki et al. (2011) that the force threshold for women should be decreased, while this paper does not address the percentage decrease of this

threshold we consider the estimated 22% on the RTs at the Beijing Olympics is relevant to all competitions. While this study has consistently reported a sex difference in RTs of athletes, this sex difference may be a consequence of the currently employed starting block sensor technology and event detection algorithms. The replacement of a force based threshold with an appropriate algorithm to detect initial rise in block force could establish whether a true sex difference exists in the RTs of athletes.

**Rule Revision**

Revised RT thresholds were established for men and women independently by estimating an EMGD fit for each of the sexes. The revised threshold was calculated as the RT for which 99% of the observed RTs lay above. Based on this and under the constraints of the currently employed starting block technology, it is suggested that the RT threshold for men be increased to 115 ms, while women should be increased to 119 ms, due to the evident sex difference reported throughout this study and in Lipps, Galecki et al. (2011).

**Technology**

This paper has presented evidence that the 100 ms ruling as a disqualification limit for false starts in elite athletics is too liberal. This needs to be considered in relation to the current technology utilised to measure an athlete's RT. The IAAF approved technology does not record the quickest RT, or the first movement of the athlete, but rather the addition of the time to produce a predefined force along with the RT. Pain and Hibbs (2007) suggested that RTs of 85 ms are possible; this paper does not contradict these findings but rather suggests that these shorter RTs are similar to the time until the initial response of an elite athlete after a start signal.

## Conclusions

From this study it is clear that the IAAF 100 ms false start threshold is inadequate for the fair and impartial refereeing of elite athletics, when using the IAAF approved starting block approved systems. Similar to the work of Lipps, Galecki et al. (2011) a sex difference has also been identified from the historic data. It is suggested that the ruling for men and women be independently revised to account for the strength differences between the sexes. Revised RT thresholds, estimated from the historical data, for both men and women are provided in the results section.

In conclusion, this study has examined a large dataset of RTs of international athletes, combined with an extensive literature review, it has shown that the current governance of false start disqualification is inadequate under the current measurement system utilised by the IAAF.

## Disclosure Statement

No potential conflict of interest was reported by the authors.

## Supplementary Material

Data and analysis scripts can be provided on request from the corresponding author.

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## Tables

- Table 1: Descriptive statistics for RTs of elite sprinters (ms).
- Table 2: Estimated parameters, distributional properties and goodness-of-fit statistics of the EMGD.
- Table 3: Probability of Superiority between distributions.  
(the 2nd group named is the “upper” distribution)

## Figures

- Figure 1: RTs across ruling periods.  
Box-and-whisker plots of valid RTs of sprinters across World and European Championships 1999-2014. The numbers circled are the number of disqualifications recorded as false starts.
- Figure 2: EMGD fits to RT data.  
Panels A and B present the estimated distributions for men and women respectively for the three ruling periods. The dotted line in each plot relates to the ruling period from 1999-2003, the dashed line represents the introduction of the group warning in January 2004, while the solid line represents the current ruling of automatic disqualification introduced in January 2010. Panels C and D present the estimated distributions for men and women respectively for first round heats and finals. The dashed line represents the first round RTs of athletes between 1999 and 2014, while the solid line represents the RTs in the finals of these same events.

Sex	Ruling Period	N	Median	95% Coverage Interval	No. False Starts
Men	1999-2003	1407	151.0	(116.0, 230.0)	1
	2004-2009	1545	155.0	(121.0, 250.0)	0
	2010-2014	1608	161.0	(128.0, 282.7)	8
Women	1999-2003	1160	153.0	(119.0, 244.0)	0
	2004-2009	1237	161.0	(126.2, 256.8)	0
	2010-2014	1602	168.0	(130.0, 278.0)	1
Total	1999-2014	8559	159.0	(122.0, 259.0)	10

Table 1: Descriptive Statistics for RT data (ms).

Sex	Ruling Period	Parameters			Properties		Goodness-of-fit	
		$\mu$	$\sigma$	$\tau$	$E(X)$	$s(X)$	$\chi^2$	p-value
Men	1999-2003	132.80	14.66	21.97	154.77	26.41	16.03	0.0136
	2004-2009	134.76	11.57	27.76	162.52	30.07	42.87	<0.0001
	2010-2014	139.95	10.92	32.33	172.28	34.12	60.25	<0.0001
	First Rounds	134.96	12.61	33.60	168.56	35.89	68.53	<0.0001
	Final Rounds	137.30	12.53	15.21	152.51	19.71	11.57	0.0723
Women	1999-2003	131.32	12.14	27.62	158.94	30.17	8.95	0.1765
	2004-2009	138.32	11.91	31.24	169.56	33.43	3.80	0.7039
	2010-2014	141.82	11.81	36.51	178.33	38.37	13.73	0.0328
	First Rounds	137.89	12.11	38.24	176.13	40.11	7.60	0.2688
	Final Rounds	136.90	14.04	24.15	161.05	27.93	7.97	0.2403

Table 2: Estimated parameters, distributional properties and goodness-of-fit statistics of the EMGD.

Sex	Comparison	Probability of Superiority
Men	1999-2003 v 2004-2009	0.591
	2004-2009 v 2010-2014	0.631
	1993-2003 v 2010-2014	0.721
	First Rounds v Finals	0.656
Women	1999-2003 v 2004-2009	0.684
	2004-2009 v 2010-2014	0.692
	1993-2003 v 2010-2014	0.745
	First Rounds v Finals	0.638

Table 3: Probability of Superiority between distributions.  
(the 2<sup>nd</sup> group named is the “upper” distribution)

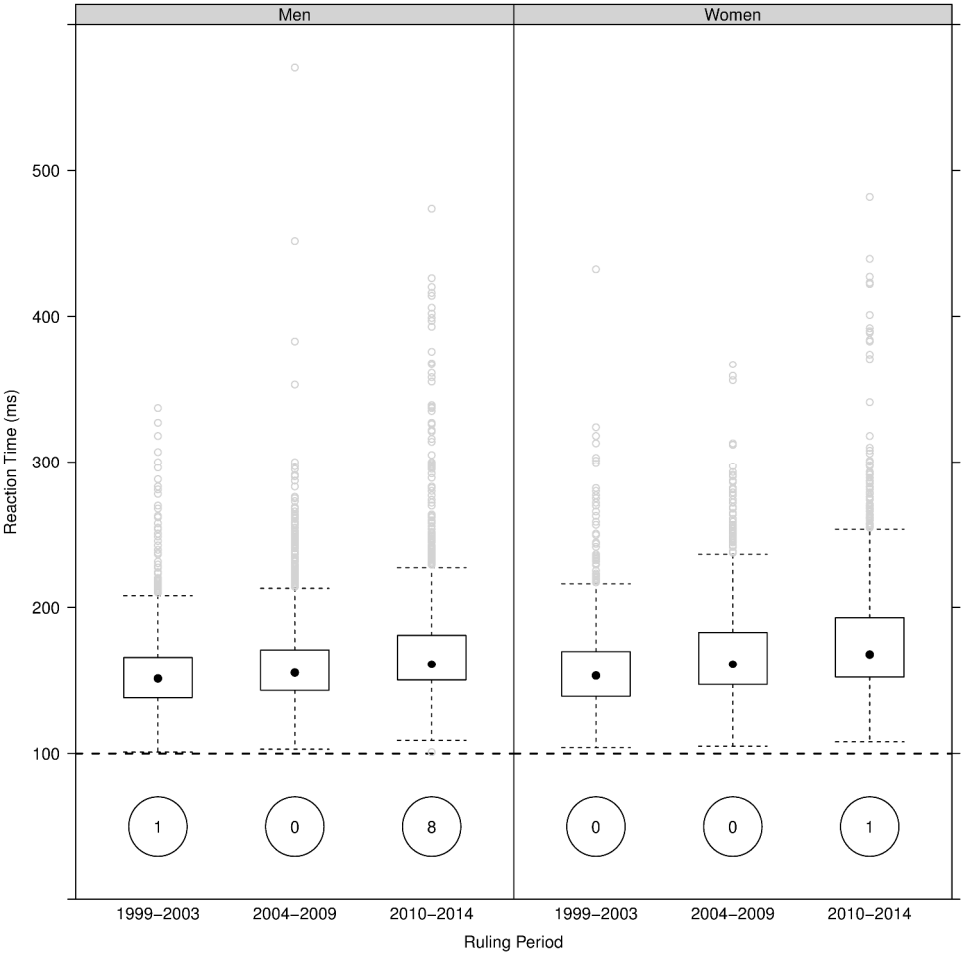


Figure 1: RTs across ruling periods.  
Box-and-whisker plots of valid RTs of sprinters across World and European Championships 1999-2014. The numbers circled are the number of disqualifications recorded as false starts.

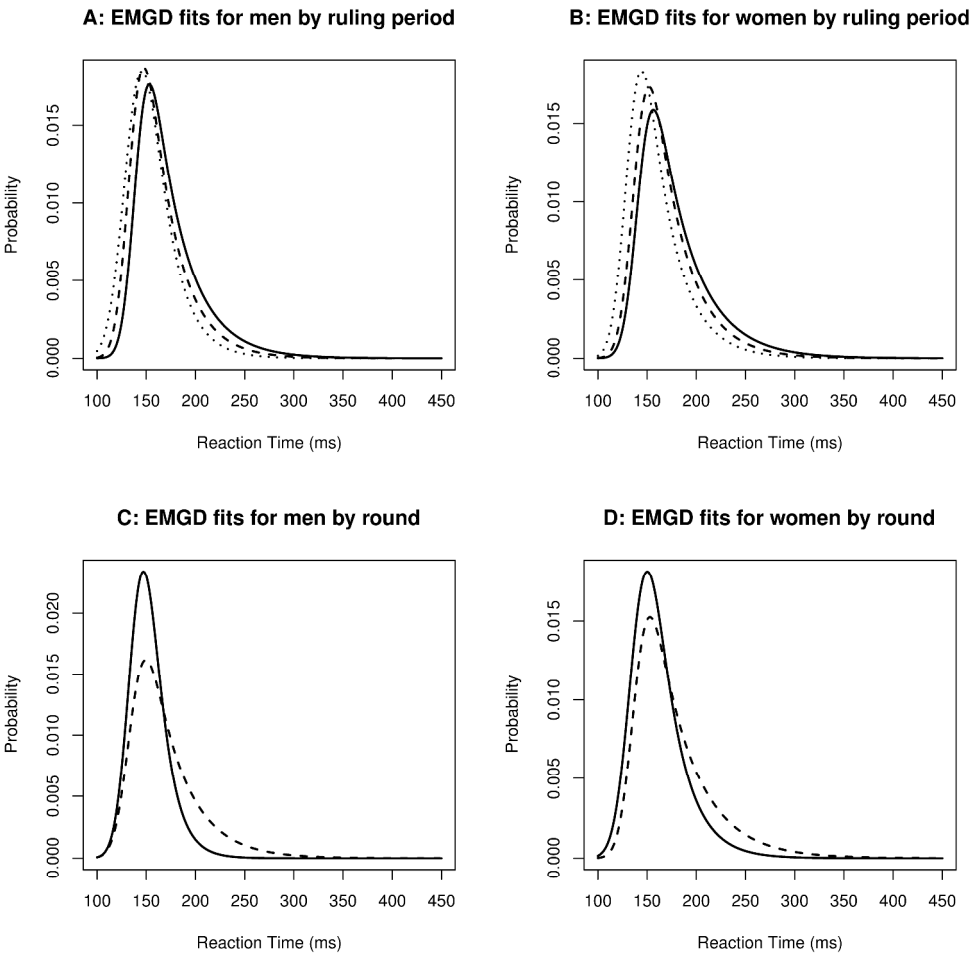


Figure 2: EMGD fits to RT data.

Panels A and B present the estimated distributions for men and women respectively for the three ruling periods. The dotted line in each plot relates to the ruling period from 1999-2003, the dashed line represents the introduction of the group warning in January 2004, while the solid line represents the current ruling of automatic disqualification introduced in January 2010. Panels C and D present the estimated distributions for men and women respectively for first round heats and finals. The dashed line represents the first round RTs of athletes between 1999 and 2014, while the solid line represents the RTs in the finals of these same events.