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

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**Abstract**

The 100 ms ruling for false start disqualification at elite 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 an athlete from an event. This paper analyses all World and European Championship reaction time data from 1999 to 2014 to examine the effect of the rule changes on competition reaction times. Initially, the identification of a difference, if it exists, between reaction times of elite athletes in different ruling periods and rounds is explored. The evidence of a sex difference in the reaction times of elite athletes is explored, with the recommendation that the disqualification ruling should be different for males and females. Finally, recommendations to the International Association of Athletics Federations are made based on the analysis of the historical data and previous similar studies.

***Keywords:*** reaction times, elite sprinters, IAAF disqualification threshold, statistical analysis, athletics

**Introduction**

The reaction times of elite 100 m sprinters has been singled out as a possible benchmark against which to gauge the absolute limits of human auditory performance (Lipps, Galecki et al. 2011). Accurately identifying the precise threshold beyond which an elite sprinter can react to the starter's pistol, and detecting occasions in competition where a highly-trained athlete has reacted so fast that (s)he must have breached this lower limit (a false start), are necessary 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 reaction time less than 100 ms (International Association of Athletics Federations 2015).

Prior to January 2004, a reaction time of less than 100 ms (i.e. a false start) resulted in a warning on a competitor and the competitor was disqualified for accumulating two false starts in the race. From January 2004, a false start by any competitor placed all the athletes in the race on a warning. Subsequently any sprinter registering a false start would be automatically disqualified regardless of whether (s)he was the original offender. Due to tactical false starts becoming prominent in sprint events, the IAAF made significant changes to the rules in January 2010 in the hope of eradicating such behaviour. Under the revised rule no warnings are issued and a competitor who false starts is automatically disqualified and removed from the race.

The first question this paper addresses is to characterise how, if at all, the IAAF rule changes have influenced the reaction times of elite sprinters in top-tier competitions. Notwithstanding empirical evidence of a sex difference in elite athletes (Lipps, Galecki et al. 2011) or in the general population (Der and Deary 2006), IAAF rule 161.2 continues to govern both male and female competitions. Moreover, Lipps, Galecki et al. (2011) also highlight that part of the IAAF justification for the 100 ms threshold is based on a considerably dated study involving eight non-elite Finish male sprinters (Mero and Komi 1990). The second question this paper addresses is whether the data collected across multiple top-tier competitions can be combined and used to revise the IAAF 100 ms reaction time threshold for male and female sprinters accordingly. A similar revision of the threshold was suggested in Komi, Ishikawa et al. (2009), where seven Finnish national-level sprinters, four male and three female, were studied. To date the IAAF have not implemented the recommendations of this study for assessing false starts, yet the findings of this paper show that the recommendations suggested by Komi, Ishikawa et al. (2009) may improve upon the current standard for the detection of false starts.

The remainder of this paper provides an in-depth analysis of a fifteen years’ worth of reaction time data. The methods section provides an overview of the collected data followed by an introduction to the statistical methods to be utilised in the analysis. The results section provides tables and figures which correspond to the application of the methodology discussed in the previous section to the sprint starts reaction time data. A discussion of these results follows providing an insight into the reaction time data across ruling periods. Finally, the conclusions are presented along with the authors recommendations to improve the fair and impartial refereeing of the false start disqualification rule in elite competitive athletics.

**Methods**

***Reaction Time Data***

The reaction time data collated from the IAAF results website (http://www.iaaf.org/results) and the European Athletics website (http://www.european-athletics.org/results/) includes complete Championship event data for the 60 m and 60 m hurdles indoor championships and the 100m, 110m 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 reaction time has less influence on the performance and therefore would not provide valid information on the quickest possible reaction time of an elite athlete. The data collected contained race RTs for 1303 and 1007 unique male and female athletes, respectively, with a total of 4560 and 3999 RT records for male and female performances respectively. While the data contains 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. To the knowledge of the authors this has been the largest exploration of reaction times of elite sprinters to date and far exceeds the work of Mero and Komi (1990) which is the basis for the 100ms threshold established by IAAF for competitive athletics or the revised IAAF study by Komi, Ishikawa et al. (2009).

***Exploratory Analysis***

Due to the non-normality of RT data, the exploratory analysis utilised the median as a measure of centrality and confidence intervals around the median at the 2.5 and 97.5 percentiles. Box-and-whiskers plots provide visualisation of the reaction times of males and females across ruling periods. The exploratory analysis also examined the number of false starts recorded in each ruling period.

***Exponentially Modified Gaussian Distribution***

The measurement and analysis of human reaction times to auditory, visual and sensory stimuli has been a significant research area in experimental psychology in the past fifty years (Hockley 1984, Luce 1986). Human reaction times have been identified as being unimodal and positively skewed, simply put many reactions are expected almost immediately after the stimulus but with a large proportion of the population reacting at a slower rate than the quickest reactors. The exponentially modified Gaussian (EMG) distribution (Dawson 1988), a mixture of an exponential distribution, controlling the tail of the distribution, and a Gaussian distribution to represent the group of quickest reactions, thus accounts for the whole population of reactions.

The EMG distribution has a probability density function

Where, µ, σ and τ parametrise the distribution and are constrained such that and , while Φ(t) is the cumulative standard normal distribution function evaluated at t. If X follows an EMG distribution with the above parameters its measure of location and scale can be represented as and , respectively. In the case of the model reduces to a Gaussian fit, while in the case of the exponential component dominates the Gaussian resulting in a point mass at µ, followed by an exponential decay.

The parameters for each of the EMG distributions reported are 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 EMG distribution are described in detail inSilver, Ritchie et al. (2009) and are implemented in the R statistical package retimes.

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

Pearson’s Chi-Squared goodness-of-fit is one of the most commonly used goodness-of-fit statistics used in the literature. The test evaluates if the observed data comes from an underlying distribution. The null hypothesis assumes that the data fits the distribution well, while the alternative assumes that the distribution is not a true reflection of the observed data, more detail can be found in Greenwood and Nikulin (1996). The goodness-of-fit statistic is approximated by the Chi-Squared distribution with degrees of freedom, where p is the number of parameters estimated from the data, while the test statistics is defined as

where *α* is the significance level to be used, *N* is the number of observations, *r* is the number of quantiles, and is the number of observed and expected observations in the quantile *i*. For this paper a significance level of will be used.

***Comparison across ruling periods and rounds***

To compare differences across ruling periods and rounds a simplistic probabilistic approach will be taken. The probability of a reaction time above a given threshold occurring can be expressed as by the total law of probability. In turn the where is the cumulative distribution function (CDF) of the EMG distribution evaluated at the value of interest . The CDF is formulated by integrating the probability density function shown above, resulting in the CDF for the EMG being

where µ, σ and τ are the parameters of the EMG and Φ is the CDF of the standard normal distribution.

**Results**

Table 1 provides basic statistics for the RTs of elite sprinters relative to rule change periods set down by the IAAF and by gender. The rows of the table represent the combination of ruling period and sex. The columns provide the number of observations, the median, a 95% confidence interval around the median and the number of false starts recorded in the period.

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

A box-and-whiskers plots for the reaction times by ruling period are presented in Figure 1. The left panel represents the male participants while the females 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 reaction times in milliseconds. The horizontal dashed line at 100 ms denotes the current disqualification limit – while reaction times are recorded below 100 ms they correspond to false starts which are not a true reflection of the shortest valid reaction times in elite athletes.

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

The results of fitting the EMG distribution for males and females 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 – as it may be that athletes are more willing to attempt to predict the starter's pistol in a race of significant value. The parameters columns presented in Table 2 provide the maximum likelihood of the best estimates of the EMG parameters given the data from the given period and gender; the properties columns shows the location and scale of the distribution, the form of which was discussed in the methods section earlier; the GoF column provides a measure of goodness-of-fit of the estimated distribution to the observed data.

\*\*\*\*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 (red) dotted line is the fit for the 1999-2003 ruling period, the (blue) dashed line is the estimated distribution for the 2004-2009 period, while the immediate disqualification ruling distribution is the (black) solid line. Panel C and D provide a visualisation of the estimated EMG fits for the first round heats, (blue) dashed line, and finals, (black) solid line, for both males and females.

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

The probabilistic approach for identifying a difference across ruling periods and rounds is carried out by calculating the probability of observing a RT greater than 120 ms. For male ruling periods the respective probabilities are 0.95, 0.98 and 1.00, female ruling period’s probabilities are 0.97, 0.99 and 1.00. The probabilities of observing reaction times above 120 ms in first rounds are 0.98 and 0.99 and in finals are 0.98 and 0.97 for males and females respectively.

**Discussion**

The 95% confidence interval about the median for the entire data shows a lower bound of 122 ms, 22 ms above the threshold set down by the IAAF. In the context of a 100 m sprint 22 ms can be a significant advantage. For example in the 2012 Olympic Games in London saw Shelly-Ann Fraser-Pryce take the gold medal in the women’s event by a winning margin of only 30 ms ahead of Carmelita Jeter. Thus an improved start regime could be the winning or losing of a 100 m sprint, particularly if the 100 ms threshold is indeed subject to not detecting valid false starts.

The median and 95% confidence band for each period (male and female) shown in Table 1 suggests shifts in the distributions of the reaction times of athletes in periods after a rule change of approximately 5 ms for males and 7.5 ms for females. The suggestion by Lipps, Galecki et al. (2011) of a possible sex difference in reaction times is evident here and can be further explained by the physiological differences between men and women, allowing men to produce the required force to reach the false start threshold quicker than women. It should be noted at this point that the 95% confidence band in each time period regardless of gender far exceeds the 100 ms rule currently enforced by the IAAF at competitive events. The summary statistics suggest an increase in the number of false starts for both genders after the immediate disqualification rule of January 2010. However, these values are biased due to the recording of only the disqualification times of athletes in previous periods and not recording the reaction times that only resulted in a warning to athletes.

While a shift in the reaction times 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, for both males and females. Another issue under consideration is the number of false starts recorded with 9 out of 10 being recorded after the rule change in 2010, for both male and female events. While this is expected due to the removal of a second chance in comparison with previous rules, the number of false starts is not recorded unless a disqualification occurs in the previous periods leading to biased numbers in the final ruling period; this was also evident in Table 1.

Table 2 and Figure 2 present the estimated fits of the EMG distribution for males and females across ruling periods and rounds. In the case of ruling periods, the centre mass of the Gaussian case in both male and female has an increasing trend as the rules change over time, which validates the discoveries made in the exploratory analysis phase. While the estimated centre of the Gaussian component, µ, appears lower for females than males this is not contradictory to the suggestion of a sex difference. The sex difference is predominately governed by the exponential shift parameter τ which is considerably higher for women across all time periods, which is further justified by the higher measure of centrality (E(X)) for women's events in comparison with men's. It is notable that the centrality measure for each of the EMG distribution fits regardless of ruling period or gender far exceeds the 100 ms ruling set down by the IAAF. In fact, in all cases excluding the men's 2010-2014 ruling period the 100 ms is approximately two standard deviations away from the centrality measure. It is evident in both genders 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 gender difference can be identified as the panels A and B of Figure 2 are on the same scale, with the females densities being shifted further to the right. A comparison of the reaction times in first round heats and finals is shown in panels C and D of Figure 2. A reduction of the reaction times in finals may suggest that athletes are more willing to engage in predicting the starter's pistol when a medal is on the line. A shift to the left indicating a decrease in reaction time is evident in both cases, thus suggesting that athletes are more likely to take risks in finals than in first round heats.

The goodness-of-fit statistics suggest that for female events the estimated EMG fits are appropriate to the data, however in the case of male events the goodness-of-fit statistics result in a p-value far below the threshold of 0.05, with exception of the final rounds. While the fits appear not to be statistically robust, visually the fits of the distribution to the data is sufficient.

The probability of observing a reaction time of greater than 120 ms increases for both males and females across the ruling periods. The probability of observations greater than 120 ms following the introduction of the automatic disqualification rule in 2010 is 1, regardless of gender. This is suggestive that the true reaction time limit of athletes recorded using the current technology is in the region of 120 ms, some 20 ms above the enforced threshold. The difference between first rounds and finals is less significant with only a relative difference being shown in female athletes, this may be due to the fact that males 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).

**Conclusions**

Throughout this paper there has been evidence that the 100 ms ruling as a disqualification limit for false starts in elite athletics is too short. However, this needs to be taken in the context of the current technology utilised to measure an athlete’s reaction time. The current method does not represent the quickest reaction time, or the first movement of the athlete, but rather the addition of the time to produce a predefined force along with the actual true reaction time. Pain and Hibbs (2007) suggest that reaction times of 85ms are possible; this paper does not contradict these findings and suggests that these reduced reaction times are similar to the time until the very first reaction of an elite athlete after a starter's pistol.

Secondly, a significant difference between male and female athletes is evident. While the Gaussian component for male and females are similar, the exponential component is considerably longer for females. Whitley, Nelson et al. (1999) provide evidence that men are more likely to have a positive attitude to cheating than that experienced by women, this along with the obvious difference in physiology to produce the required force, provides an explanation of the evident difference across gender.

Finally, there is evidence of a shift in the reaction times of athletes between first round heats and finals. While it is not clear if this shift is simply due to the quality of the athletes being less variable in finals, it can be seen that the change in females is much larger than that in male events. This would again verify the evidence of a sex difference being relied on not only from a physiology standpoint but also with relation to the behavioural attitude of males towards cheating as outlined in Whitley, Nelson et al. (1999), with women only more likely to take a risk in races of significance.

From the exploration of historical data for the reaction time of elite athletes, in conjunction with a thorough review of the current literature, the following are the authors’ recommendations relating to the sprint start disqualification threshold.

***Sex Difference in Reaction Times***

The current position of providing a single rule for males and females in elite-athletics has been shown to be inadequate. The physiological differences in muscle strength between males and females make the reaction of women slower to reach a required force threshold than men. This explains the difference in reaction times across gender shown throughout this paper and also reported in Lipps, Galecki et al. (2011) and Der and Deary (2006). A reduction of the force required for women proposed by Lipps, Galecki et al. (2011) appears to be the most appropriate change if no change in the measurement system or technology was to be considered by the IAAF.

***Measurement System & Technology***

The measurement system currently used across top-tier athletics is not standardised which adds additional variation to the recorded reaction times. The detection limit is calculated as the time at which an athlete exceeds a force threshold on the starting blocks. This threshold approach is not a true reflection of the absolute speed of human reaction times. A more appropriate measure would be the first muscle reaction of an athlete after the starter's pistol, this could be measured using laser or radar technology or using high speed cameras as suggested in Komi, Ishikawa et al. (2009). Pain and Hibbs (2007) suggest that reaction times for elite athletes could be as low as 85ms; this is possible if the time until the very first reaction of the athlete (regardless of body part) is measured rather than the time to produce a pre-defined force on the starting blocks.

***Real-Time Analysis of Current Measurement System***

Using the current technology employed by the IAAF for elite athletics it is proposed that an automated statistical methodology be used to monitor the change in pressure on the starting blocks in real-time. This would be reflective of the first reaction of an athlete and any such change in force prior to the starter's pistol should be deemed a false start. While an improvement in the technology would be a more effective approach, utilising methods in real-time would no doubt increase the detection of true false starts. This approach would not be constrained by a defined pressure threshold, but rather be governed by the identification of a change-point in the pressure function, thus generalising usability across all athletes, eradicating the gender difference proposed by Lipps, Galecki et al. (2011).

**Disclosure Statement**

No potential conflict of interest was reported by the authors.

**Supplementary Material**

Supplement A: Reaction Time Data 1999-2014. (<https://goo.gl/9XcL1K>; .csv)

Supplement B: R Code for Reaction Time Analysis. (<https://goo.gl/nghq3O>; .R)

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**Tables**

* Table 1: Descriptive statistics for reaction times of elite sprinters (ms).
* Table 2: Estimated parameters and distributional properties of the Exponentially Modified Gaussian distribution.

**Figures**

* Figure 1: Reaction times across ruling periods.

Box-and-whiskers plot of valid reaction times of sprinters across World and European Championships 1999-2014. The numbers circled are the number of disqualifications recorded as false starts (this is not the same as the number of athletes disqualified or the number of false starts in the 1999-2003 or the 2004-2009 ruling periods).

* Figure 2: Exponentially Modified Gaussian distribution fits to reaction time data.

A and B present the estimated distributions for males and females respectively for the three ruling periods. The (red) dotted line in each plot relates to the ruling period from 1999-2003, the (blue) dashed line represents the introduction of the group warning in January 2004, while the (black) solid line represents the current ruling of automatic disqualification which was introduced in January 2010. C and D present the estimated distributions for males and females respectively for first round heats and finals. The (blue) dashed line represents the first round reaction times of athletes between 1999 and 2014, while the (black) solid line represents the reactions time in the finals of these same events.



Table 1



Figure 1



Table 2



Figure 2