THE PREDICTIVE MODEL OF INTERVAL TIME BASED ON PACING STRATEGY IN A 400 M HURDLES RACE

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The purpose of the present study was to verify the reliability of the prediction equation for interval time (the times between hurdles) established from the hierarchical model in the 400 m hurdles. From 155 data samples of previous studies (record range: 47.42–50.99s), regression equations were established to predict each interval time throughout the race (model #1), during the first and latter halves (model #2) and during the first, middle, and last parts (model #3). Leave-one-out cross-validation was used to avoid overtraining for each regression equation. Models #2 and #3 showed better goodness of fit and generalization for each interval time compared to model #1. These hierarchical models are found to be more reliable compared to the non-hierarchical model. The hierarchical model will help to set the pace distribution to achieve the athlete's target records accurately.

KEYWORDS: statistical model, cross-validation, hierarchical model

INTRODUCTION: Spatiotemporal variables in hurdle events have been recognized as important parameters (Otsuka & Isaka, 2019), by which the hurdlers can acknowledge and modify their race characteristics. Coaches often use temporal parameters in their daily training sessions as a target of training. The models that are based on vast race statistics would provide more accurate temporal parameters to make daily training interventions more effective (Iwasaki et al, 2022). Recently, Iwasaki et al. (2022) established a reliable statistical model of touchdown times of the 110 m hurdles race using a non-hierarchical model. However, there has been no reliable statistical model for the 400 m hurdles, to date.
In a 400 m hurdles race, hurdlers regulate their running pace during the race in order to achieve better results (Otsuka & Isaka, 2019). Several studies have shown that elite 400m hurdlers adopt various pacing strategies (Otsuka & Isaka, 2019; Iskra et al., 2021). To establish the pacing strategies of a 400 m hurdles race, accurately identifying the interval times (the times between hurdles) is essential and would be useful information for coaches and hurdlers. Since the 400 m hurdles are required to adapt different pace strategies to cover several sections within the race distance, a hierarchical model could be well suited to establish a better statistical model of the 400m hurdles race. In the 400 m hurdles race, hierarchical modelling could be done by dividing the race into several sections. A statistical model that considers pacing would allow for setting time goals accurately for training sessions and evaluating the actual interval times during races in comparison to theoretical values derived from the model. This statistical model would be a great help for the 400 m hurdlers to achieve their target times. We aimed to establish a reliable statistical model for the 400 m hurdles race with a hierarchical model. Thus, the present study aimed to verify the reliability of the prediction equation for interval time established from the hierarchical model in the 400 m hurdles. We hypothesised that a hierarchical model would have less error than a non-hierarchical model.

METHODS: We obtained 155 data samples, including resultant race times, touchdown times and interval times, from previous studies (Ditroilo & Marini, 2001; Graubner & Nixdorf, 2011; JAAF, 2018, 2019, 2020; Kakehata et al., 2019; Morioka et al., 2018a, 2018b; Sugimoto et al., 2020a, 2020b, 2021). These data were obtained from male competitions of 400 m hurdles (mean race time: 49.72 ± 0.88 s, range: 47.42–50.99 s). Most of the data used in the analysis were final round data, but some semi-final round data were also included. We established the statistical model to estimate the interval times in three ways: #1) the model to predict each interval time from the resultant race time, #2) the model to predict the first (start–5th hurdle) and latter (5th hurdle–finish) halves of the race times (Otsuka & Isaka 2019), and #3) the model to predict the first part (start–4th hurdle), the middle part (4th hurdle–7th hurdle) and the last part (7th hurdle–10th hurdle) of the race (Iskra et al., 2021) (Figure 1). For these models, regression equations were established to estimate each interval time from the resultant race times or the time in each divided section. To avoid overfitting for each regression equation, leave-one-out cross-validation (*LOOCV*) was performed (Iwasaki et al., 2022). Since we have 155 regression equations per interval and section, we report the averaged equation to show the trained regression models. For each equation, we calculated the coefficient of determination (R^2) of the linear regression, the mean squared error (*MSE*) and the mean absolute error (*MAE*) from *LOOCV*. To compare the *MSE* and *MAE* of each interval between the three models, Student's *t*-tests were used (p < 0.05). The alpha level of each *t*-test was adjusted with the Bonferroni method. These procedures were fully described in a previous study (Iwasaki et al., 2022). These processes were implemented with R (Austria, version 4.2.1).

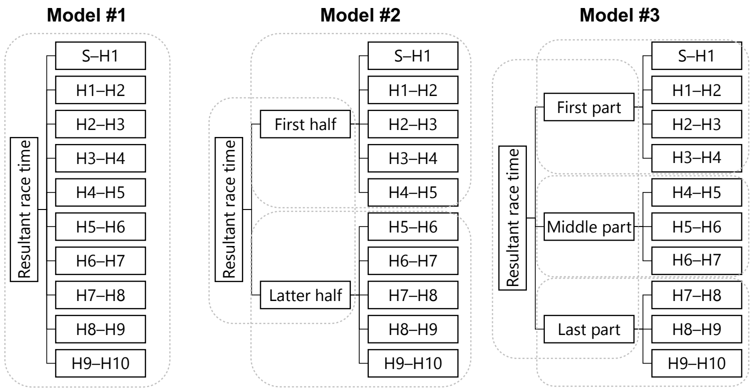

Figure 1: Three models established in the present study
S: Start, H: Hurdle (i.e., H1 = 1st hurdle)

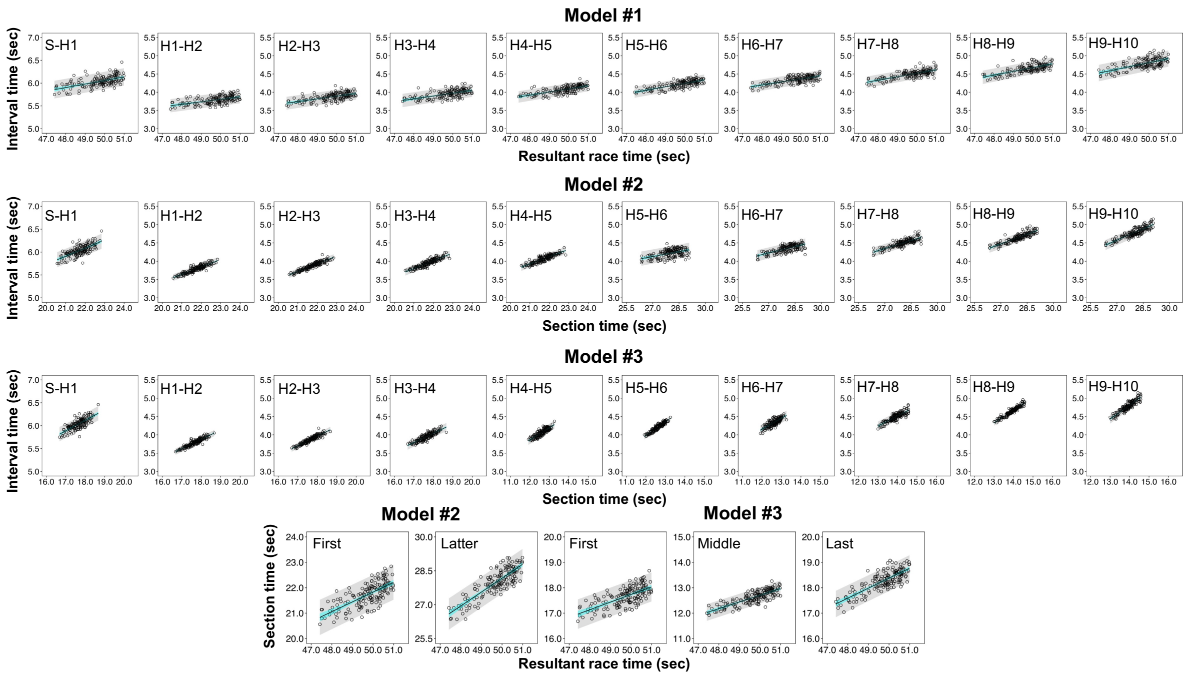

Figure 2: Scatter plot of interval time against resultant race time/section time, and section time against resultant race time. Shaded areas in blue indicate the 95% confidence interval for regression lines. Shaded areas in grey indicate the 95% prediction interval for estimated values.

RESULTS: As shown in table 1, significant regression equations were obtained in all the models (p < 0.05). Figure 2 shows the scatter plot of interval times against resultant race time/section time, and section time against resultant race time in each model. Table 2 compares the goodness of fit and generalization in each regression equation between the three models. Overall, the model #3 yielded a higher R^2 and lower generalization index (*MSE*, *MAE*) in each interval time. For *MSE* and *MAE*, the mean values of *MSE* and *MAE* were significantly lower in the models #2 and #3 than those in the model #1 ($p < 0.05$).

Table 1. Comparison of the equations between the three models

	Equations		
	#1	#2	#3
First	–	0.3851 *x* + 2.5739*	0.2992 *x* + 2.7754*
Middle	–	–	0.2633 *x* – 0.4631*
Latter (Last)	–	0.6149 *x* – 2.5739*	0.3105 *x* – 1.5143*
S–H1	0.0779 *x* + 2.1623*	0.1763 *x* + 2.2085*	0.2292 *x* + 1.9919*
H1–H2	0.0683 *x* + 0.3926*	0.2025 *x* – 0.6096*	0.2549 *x* – 0.7110*
H2–H3	0.0751 *x* + 0.1405*	0.2108 *x* – 0.7058*	0.2619 *x* – 0.7492*
H3–H4	0.0779 *x* + 0.0799*	0.2114 *x* – 0.6387*	0.2541 *x* – 0.5316*
H4–H5	0.0859 *x* – 0.2015*	0.1991 *x* – 0.2545*	0.3303 *x* – 0.1021*
H5–H6	0.0940 *x* – 0.4576*	0.0882 *x* + 1.7460*	0.3717 *x* – 0.4781*
H6–H7	0.0834 *x* + 0.1960*	0.1168 *x* + 1.0724*	0.2979 *x* + 0.5802*
H7–H8	0.0955 *x* – 0.2548*	0.1483 *x* + 0.3434*	0.2729 *x* + 0.6946*
H8–H9	0.1038 *x* – 0.5110*	0.1763 *x* – 0.2879*	0.3459 *x* – 0.1680*
H9–H10	0.1112 *x* – 0.7485*	0.2060 *x* – 0.9852*	0.3812 *x* – 0.5266*

S: Start, H: Hurdle (i.e., H1 = 1st hurdle), *: $p < 0.05$

Table 2. Comparison of the goodness of fit and generalization in each equation between the three models

	R^2			*MSE*			*MAE*		
	#1	#2	#3	#1	#2	#3	#1	#2	#3
First	–	0.484	0.446	–	0.118	0.083	–	0.281	0.241
Middle	–	–	0.665	–	–	0.027	–	–	0.130
Latter (Last)	–	0.709	0.582	–	0.118	0.052	–	0.281	0.186
S–H1	0.321	0.506	0.561	0.009	0.007	0.006	0.078	0.063	0.060
H1–H2	0.294	0.814	0.842	0.008	0.002	0.002	0.074	0.036	0.032
H2–H3	0.351	0.857	0.863	0.008	0.002	0.002	0.071	0.032	0.030
H3–H4	0.352	0.803	0.755	0.008	0.003	0.003	0.072	0.040	0.044
H4–H5	0.475	0.777	0.737	0.006	0.003	0.003	0.061	0.040	0.046
H5–H6	0.538	0.237	0.881	0.006	0.009	0.001	0.061	0.081	0.031
H6–H7	0.466	0.482	0.620	0.006	0.006	0.004	0.062	0.062	0.051
H7–H8	0.534	0.686	0.718	0.006	0.004	0.004	0.059	0.049	0.047
H8–H9	0.493	0.764	0.912	0.008	0.004	0.001	0.071	0.048	0.029
H9–H10	0.423	0.785	0.830	0.013	0.005	0.004	0.091	0.055	0.049
Mean (SD)	0.425 (0.085)	0.671 (0.189)	0.785 (0.092)	0.008 (0.002)	0.004* (0.002)	0.003† (0.001)	0.070*,† (0.009)	0.050* (0.014)	0.042† (0.010)

S: Start, H: Hurdle (i.e., H1 = 1st hurdle), MSE: Mean squared error, MAE: Mean absolute error, *: $p < 0.05$ (#1 vs #2), †: $p < 0.05$ (#1 vs #3).

DISCUSSION: The present study aimed to verify the reliability of the prediction equation for interval time established from the hierarchical model in the 400 m hurdles. The results showed that the mean squared error (*MSE)* and mean absolute error (*MAE)* in the models #2 and #3 were significantly lower than those of the model #1 ($p < 0.05$). In addition, the goodness of fit (R^2) in the models #2 and #3 were also higher than that of the model #1. These results supported our initial hypothesis that the hierarchical model (model #2 & #3) would show a better prediction and generalization performance than the non-hierarchical model (model #1). Pacing strategy is an important element in a 400 m hurdles race (Otsuka & Isaka, 2017; Iskra et al., 2021). Thus, hurdlers choose a pacing strategy that suits them during a race. This means that the variance of times in each interval between hurdles would be large, and a non-hierarchical model that does not account for the change of pace would not provide adequate prediction equations. Hierarchical models can help to provide the necessary theoretical basis

for examining the relative importance of various factors that affect the outcome (Chow & Knudson, 2011). Therefore, the hierarchical model likely improves the reliability of the prediction equations for each interval time. As elite 400 m hurdlers often choose an endurance strategy (Iskra et al., 2021), the times in the latter parts of the race explained about 60–70% of the resultant race time (R^2; model #2 = 0.709, model #3 = 0.582). Iskra et al. (2021) described the pacing strategy varied in three divided parts and reported that the middle part of the race is a technical stage for athletes who are good at switching number of strides between hurdles. In the model #2, the race was split into halves, resulting in a lower goodness and generalization performance during the middle part of the race (around the 5th to 7th hurdles), compared to the model #3. The hierarchical model divided into three sections was found to be the most reliable one for the prediction of the interval times in 400 m hurdles verified in the present study. The model #3 proposed in the present study is expected to be used as fundamental data for planning pacing strategies during a 400 m hurdles race. It could also be used to evaluate training sessions and achieve effective interventions.
The present study is not without limitations. The model established in the present study was only modelled following previous studies. Further research would be needed that also considers the evaluation of different modelling approaches.

CONCLUSION: The predict model established from three hierarchical structures demonstrated a clear advantage for the predicting performance of interval times in the 400 m hurdles. It is expected to be used for pacing strategies and effective training interventions.

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