Brief Paper

Prediction of swim performance in junior female swimmers by dynamic system model

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The purpose of this study was to determine the validity of a dynamic system model that predicts fluctuations in swim performance in junior female swimmers based on the dose-response relationship between training and performance. Two female swimmers, Sub.1 (age: 17 yrs, height: 168.0 cm, weight: 63 kg) and Sub.2 (age: 15yrs, height: 155.0 cm, weight: 51 kg) participated in this study. Their training and swim performance were monitored for 134 days. Training quantity was defined as a product of the intensity and distance of the swim training; intensity and distance were measured at every training session. Training intensity was determined by blood lactate levels and the unit of distance was kilometers. In order to determine swim performance, subjects were directed to perform a 200 m free-style swim test every 2 weeks. A dynamic system model that was composed of two exponential components (fitness component and fatigue componetnt) was applied to the relationship between training and performance. For each subject, parameters of the model were estimated using the non-linear least square method. Predicted performance by the model was compared with measured performance. For both subjects, the predicted values showed a significantly higher goodness of fit with measured performance (Sub.1: r^2 = 0.803; Sub.2: r^2 = 0.716). The range of prediction residual of the model was smaller than the range of random error in day-to-day, and there was no systematic bias in the distribution of prediction residuals. Therefore, the dynamic system model is judged to be a valid predictor of swim performance fluctuation in junior female swimmers.

Key words : modeling, training, stress index, dose-response

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1. Introduction

Performance in the swimming events is closely related to the condition of the swimmer (Mujika et al., 1995). For this reason, in order to elicit optimum swimmer performance for the target event, it is important to control the swimmer's condition. It is known that athlete condition and training quantity exhibit a dose-response relationship (Banister et al., 1975; Calvert et al., 1976; Morton et al., 1990; Busso et al., 1990; Mujika et al., 1995) and in order to optimize the swimmer's condition, it is necessary to evaluate the daily training and variation in the condition along with training both objectively and quantitatively.

To quantitatively evaluate the dose-response relationship between training quantity and condition, a dynamic system model has been developed (Banister et al., 1975; Calvert et al., 1976; Morton et al., 1990; Busso et al., 1990). The dynamic system model shows the relationship between the condition or performance and the quantity of training, which is modeling by a simultaneous ordinary differential equation as a summation of greater than two components that range dynamically (Banister et al., 1975; Calvert et al., 1976). Moreover, Morton et al. (1990) and Busso et al. (1990) converted the ordinary differential equation model into an exponential model and expanded the utility of the analysis. Also, it became easier to estimate model parameters statistically in the exponential model by the non linear least squares method.

In general, the exponential model of the dose-response relationship between training and performance constructs performance by fitness component and fatigue componetnt (Morton et al., 1990; Busso et al., 1990). Fitness component is a concept (arbitrary unit) that represents a positive reaction of the performance to the training, and fatigue componetnt is a concept (arbitrarily unit) the represents a negative reaction to the training (Eq.1, Eq.2).

$$g(t) = g(t-i)e^{\frac{-i}{\tau_1}} + w(t) \cdots \text{Eq.1}$$

$$h(t) = h(t-i)e^{\frac{-i}{\tau_2}} + w(t) \cdots \text{Eq.2}$$

Here, g(t) and h(t) represent the response of fitness component and fatigue componetnt at the point t, i is training interval and τ_1 and τ_2 represent the time delay (time constant) to the training of fitness component and fatigue componetnt. Also, w(t) is training quantity at the point t. In this exponential model, it is assumed that the fatigue componetnt response is faster than that of the fitness component, that is $\tau_1 > \tau_{2,}$ and it is also assumed that the difference of fitness component and the fatigue componetnt correspond approximately to actual performance (Morton et al., 1990) (Eq.3).

$$p(t) = k_1 g(t) - k_2 h(t) \cdots \text{Eq.3}$$

Here, p(t) is a prediction value of the performance at point t, k_1 and k_2 are the weighting coefficient of fitness component and fatigue componetnt, assumed as $k_1 < k_{2.}$

The criterion-related validity of the dynamic system model was confirmed by the degree of agreement (coefficient of determination) of measurement performance and predicted performance estimated by the model (Morton et al., 1990). In addition, the dynamic states of the fitness component and the fatigue componetnt to the training correspond with the response of hormonal secretion toward each component (Busso et al., 1990) and this clarifies the content validity of the dynamic system model.

The training quantity that can cause fitness component and fatigue componetnt in the dynamic system model is given as a product of the training intensity and the training time. In the measured index of the training, intensity is often described by the relative value (%$\dot{V}O_2$max) of maximal oxygen uptake ($\dot{V}O_2$max) and variation of heart rate during the training (Morton et al., 1990; Busso et al., 1990). Also, Mujika et al. (1996) reported the usability of stress indexes (SI) (Mujika et al., 1995) that are often used in swimmer training plans as indexes of training intensity. Mujika et al. (1996) proved by the dynamic system model that optimum swimmer condition was influenced not only by a high level of training intensity, but also the appropriate tapering of the training intensity.

In the dynamic system model, the parameters of $\tau_{1,}$ $\tau_{2,}$ $k_{1,}$ k_2 that are included in Eq.1, Eq.2, and Eq.3 are assumed by the Levenberg-Marquardt method. Morton et al. (1990) who analyzed the relationship between long distance performance and training quantity for middle-aged males reported that the $\tau_1$and τ_2 of males in their 50's were 50 days and 11 days, respectively, and that the $\tau_1$and τ_2 of males in their 40's were 40 days and 11 days, respectively. In addition, an analysis of young males as targets by Busso et al. (1991) revealed that the $\tau_1$and τ_2 were 38 days and 2 days, respectively. Considering the results of these earlier studies, it is estimated that a time constant which is a parameter that shows the speed of the reaction of fitness component and fatigue componetnt that constructs the dynamic system model is smaller in young males and larger in middle- aged males.

The target of competitive swim performance prediction by the dynamic system model that have been reported to date is limited to adult swimmers (Mujika et al., 1996). To expand the usability and the utility of the dynamic system model to include competitive swim event, it is necessary to examine the validity of the dynamic system model for junior swimmers and female swimmers. Therefore, in this study, I aimed to examine the prediction validity of the dynamic system model for junior female swimmers.

2. Methods

2.1. Subjects

Subjects in this study were 2 female high school swimmers. Table 1 shows the subject details at the time measurement started. The specific event for Sub.1 was a short distance freestyle event, and the event for Sub.2 was an intermediate distance freestyle event. The test subjects thoroughly understood the content of the study content and agreed to participation.

2.2. Measurement of training quantity

Training quantity, the independent variable in the dynamic system model, is the product (Total swimming stress: SS) of SI, an index of the training intensity and distance (km). SI is calculated by dividing blood lactate concentration (La), estimated from swimming speed, (Mujika et al., 1995). With reference to the method proposed by Mujika et al. (1995), I divided the training strengths into the following five categories to estimate La.: Strength1) swimming speed below onset blood lactate accumulation (OBLA) ≒ La 2.0 mmol/l; Strength2) swimming speed corresponding to OBLA ≒ 4.0 mmol/l; Strength 3) swimming speed that is slightly faster than OBLA ≒ 6.0 mmol/l; Strength 4) swimming speed that has a high accumulation of La ≒ 10.0 mmol/l; and Strength5) maximal effort of sprint training ≒ 16.0 mmol/l. I calculated SI through La estimated by dividing each swimming speed by two. That is, calculated SI shows values of 1, 2, 3, 5, 8. The estimated La is divided by two to make it easier to handle as an index (Mujika et al., 1995). The product of each training distance and SI is the TSS.

2.3. Period and method of observation

Observational items regarding the training contents were SI, the swimming distance and the iteration count. These items were recorded individually by the test subjects every day. I examined the total swimming distances per day from the iteration count of each swimming distance. I created record forms so that the test subjects could note training content for each day. I recovered the forms directly from the test subjects once each week.

In order to set SI for each test subject, I carried out a multi stage incremental load tests on the initial day of measurement and every four weeks thereafter. These consisted of 200m freestyle speed tests of incremental exercise carried out four times. The test subjects were instructed to swim at a speed 30 seconds slower than their personal record in a 200m freestyle after warm up. For the first through the third gradual increase loading tests, I instructed the test subjects to reduce the target swimming time by 10 seconds each, and to swim at an even pace in each test. For the fourth gradual increase loading test swimming trail, I instructed the test subjects to swim at their maximal effort. After each swimming trial, I collected a small blood sample from the test subjects' ear lobes and measured La using a Simplified Blood Lactate Test Meter (Lactate Pro, ARKREY Inc. Kyoto, Japn). Each swimming trail was carried out in 15 minutes cycles, and before the last swimming trail, the subjects took a rest period of 15 to 20 minutes. I examined SI by exponential regression expression setting La in the exercise load test as a dependent variable and swimming speed as an independent variable. The standard of adoption of curvilinear regression is set over determination coefficient $r^2 = 0.98$. From the relationship between the swimming speed and La, I classified SI into five steps and calculated the limit time in each step.

2.4. Performance test

As a validity criterion for performance variation prediction by the dynamic system model, I carried out measurements of the 200m freestyle at approximately two-week intervals beginning with the start of training. The measurement values were converted into International

Table 1. Initial characteristics of subjects.

						200 m Front Crawl					
	Sex	Age	Height	Weight	Competition	Record time			IPS	Special swimming event	
		(yr)	(cm)	(kg)	(yr)	m -	ss -	00			
Sub.1	F	17	168.0	63.0	5	2	23	20	518	Free style	50, 100m
Sub.2	F	15	155.0	51.0	5	2	36	20	399	Free style	200, 400m

Point Scores (IPS), a comparative evaluation index from the world record. The conversion formula is as described below.

$$IPS = 1000\left(\frac{B}{T}\right)^3 \quad \bullet\bullet\bullet \text{ Eq.4}$$

Here, B is the average swimming time of the top world rankings up to 10th position and T is a swimming time (seconds). IPS makes the average swimming time of the top 10 world rankings 1000 and IPS has a range of 0 to 1100. In this study, I made the 200m freestyle base time of the FINA Point Scoring 2004 short course as B.

2.5. Modeling and statistical analysis

With reference to the method proposed by Morton et al. (1990), I carried out an estimation of the parameters of the dynamic system model. In Eq.1 and Eq.2, if I grant for descriptive purposes the training interval of one day (i=1), and the training quantity w (t), which is an independent variable as an optional fixed number, then Eq.1and Eq.2 will be as shown in the following equation.

$$g(t) = g(t-1)e^{\frac{-1}{\tau_1}} + T$$

$$g(t) = e^{\frac{-1}{\tau_1}}[g(t-2)e^{\frac{-1}{\tau_1}} + T] + T \quad \ldots$$

$$g(t) = T[1 + e^{\frac{-1}{\tau_1}} + e^{\frac{-2}{\tau_1}} + \cdots + e^{\frac{-(t-1)}{\tau_1}}]$$

$$g(t) = T\frac{1-e^{\frac{-t}{\tau_1}}}{1-e^{\frac{-1}{\tau_1}}} \bullet\bullet\bullet \text{ Eq.5}$$

$$h(t) = T[1 + e^{\frac{-1}{\tau_2}} + e^{\frac{-2}{\tau_2}} + \cdots + e^{\frac{-(t-1)}{\tau_2}}]$$

$$h(t) = T\frac{1-e^{\frac{-t}{\tau_2}}}{1-e^{\frac{-1}{\tau_2}}} \bullet\bullet\bullet \text{ Eq.6}$$

By Eq.5, and Eq.6, Eq.3 can be shown in the following equation.

$$p(t) = k_1 T\left[\frac{1-e^{\frac{-t}{\tau_1}}}{1-e^{\frac{-1}{\tau_1}}}\right] - k_2 T\left[\frac{1-e^{\frac{-t}{\tau_2}}}{1-e^{\frac{-1}{\tau_2}}}\right] \bullet\bullet\bullet \text{ Eq.7}$$

In this study, I estimated τ_1, τ_2, k_1 and k_2 of each test subject using Eq.7. To estimate the parameters, I set a dependent variable as the actual measurement IPS and followed the Levenberg-Marquardt method. KaleidaGraph software (SYNERGY SOFTWARE Technologies,Inc., Pennsylvania, USA) was used for the calculation.

With reference to the method proposed by Morton et al. (1990), after deciding the parameters, T, the constant from Eq.7, was replaced with TSS, a variable of the actual measurement, and I calculated the performance predictive value p(t). The predictive validity of the model was determined by the coefficient of p(t) toward validity criterion IPS, coincidence between validity criterion and a model in the residual error plot, and the possibility of systematic error. Also, to make it possible to compare p(t) and IPS, I used a regression line and converted p(t) to IPS measure. Statistical significant level was set to $\alpha = 0.05$ in all tests. I used MS-Excel for the calculation of p(t) and statistical analysis for predictive validity.

3. Results

3.1. Performance test

The observation period was 134 days in total; namely, 10 weeks from the first to the 71st day of the general preparation phase, and 9 weeks from the 72nd to the 134th day of the specific preparation phase. The total swimming distances for each test subject in the general preparation phase were 218.5km and 204.6km, the total swimming distances in the specific preparation phase were 237.4km and 189.7km, and the total swimming distances for the entire measurement period were 455.9km and 394.3km. Figure 1 shows the TSS in the observation period. The frequencies of practice per week were 5.1 and 4.2 times. The average swimming distances per time were 4.7km and 4.9km. Camp training was held from the 28th to the 31st day and from the 125th to the 128th day. TSS increased when the test subjects participated in practice twice per day and during the camp training. The total training content and the gradual increase loading tests were carried out during the training period.

Missing or abnormal performance test values were the result of test subjects becoming cold, being injured, deconditioning and various other reasons. The missing values were not complemented, and the values which were judged to be abnormal were eliminated from the data prior to analysis. In the observation period, the IPS of Sub.1 was 577±41 and the IPS of Sub.2 was 445±28.

3.2. Model parameters

Table 2 shows the parameters of each test subject in the system model. $\tau_1$in Sub.1 and Sub.2 were 21days and 29days, respectively. τ_2 in Sub.1 and Sub.2 were 6 days and 4 days, respectively. The values for τ_2 in Sub.1 were $k_1 = 1.2$, $k_2 = 2.4$, those for Sub.2 were $k_1 = 0.9$, $k_2 = 1.3$.

3.3. Validity of the performance variation prediction system model

Figure 2 shows the IPS and variation of p(t) in Sub.1 and Sub.2. The coefficient of determination of p(t) toward IPS in Sub.1 was $r^2 = 0.803$ ($P < 0.05$). The coefficient of determination in Sub.2 was $r^2 = 0.716$ ($P < 0.05$). Figure 3 shows the residual error plot of p(t), which was converted into IPS and IPS measurements. The 95% confidence interval(CI) for Subjects 1 and 2 was 577±33 and 445±33, respectively, and the significant systemicity in the error was not accepted ($r = 0.06$, $P > 0.05$).

4. Disccusion

The major finding of this study was that the coefficient of determination of the predicted performance value p(t) using SI toward IPS of the performance showed a value approximately equal to the result obtained by Morton et at.(1990) that used HR. Also, with the result of the analysis of the residual error plot, the 95%CI (Sub.1: 577±33, Sub.2: 445±33) for the system model is smaller than the 95%CI (Sub.1: 577±82, Sub.2: 445±55) of the actual IPS measurement, and it can be estimated within the range of day-to-day variability.

Moreover, the systemicity in the predictive residual error of the dynamic system model was not accepted. These results prove that the performance variation of the junior female swimmers by the dynamic system model in the case that exercise intensity was described by SI is

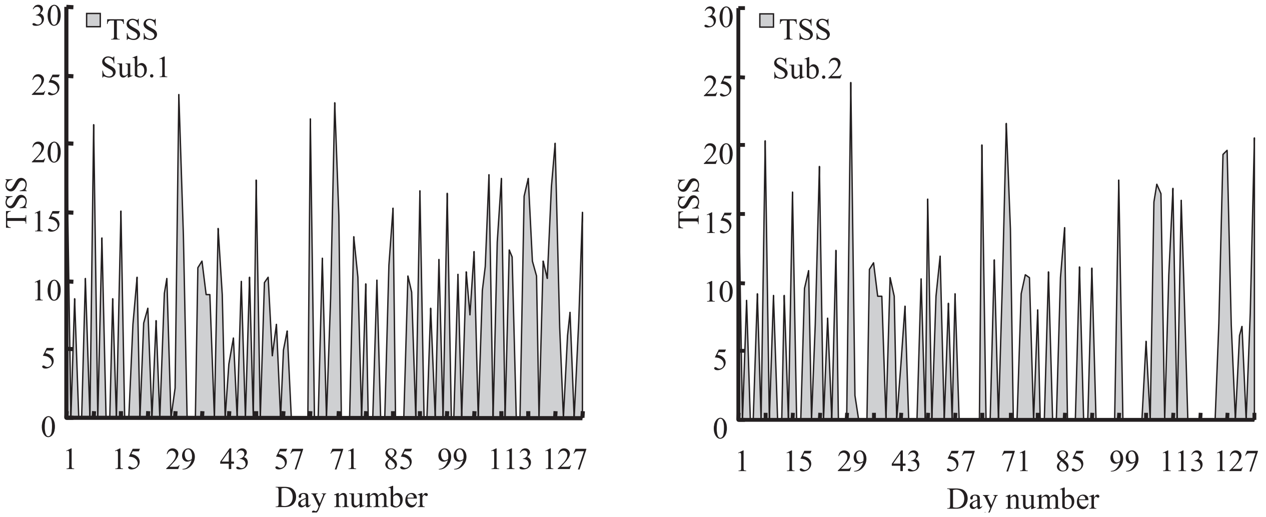

Figure 1. Changes of daily TSS for each subject. Areas show daily TSS.

Table 2. Estimated parameters for non - linear least squares method

	k_1	τ_1(days)	k_2	τ_2(days)
Sub.1	1.2	21	2.4	6
Sub.2	0.9	29	1.3	4

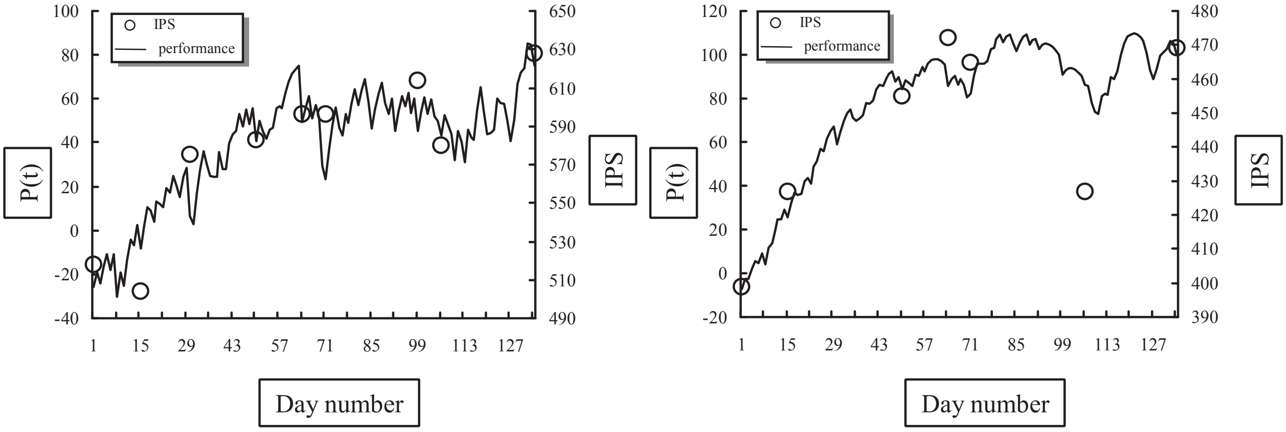

Figure 2. Fitting of predicted performance (p(t)) to measurement (IPS) for Sub.1 (left) and Sub.2 (right). Open circle symbol (○) represents IPS, and solid line shows p(t).

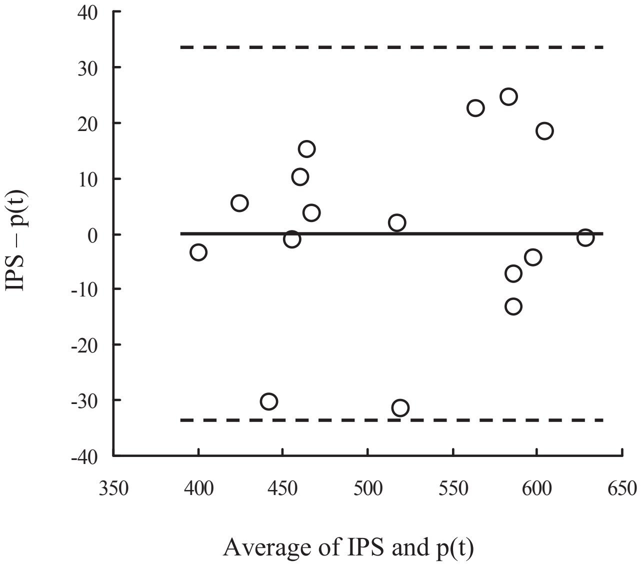

Figure 3. Residual plot between the IPS and p(t). Solid horizontal lines represent the mean difference between the p(t) and IPS, dashed horizontal lines represent the 95% confidence interval. Correlation coefficients between mean measurements the IPS and residual were r = 0.06 (P > .05).

validly predictable.

The time constant τ_1 of fitness component in this study was 21days for Sub.1 and 29 days for Sub.2.This result was smaller compared with the values (40 days and 50 days) obtained by Morton et al. (1990) for two males aged 42 years and 57 years, respectively, and Busso et al. (1991), who reported values for 8 males aged 19 to 22 years showing 38±9. In addition, the time constantτ_2 of fatigue componetnt (Sub.1: 6 days ;Sub.2: 4 days) was also a smaller value, as was $\tau_{1,}$ compared to τ_2 at11days in the earlier studies (Morton et al., 1990).

The fact that the time constants of fitness component and fatigue componetnt are both small suggests that the effect of the training effect is quickly expressed. Ikai (1967) and Wanne and Valimaki (1983) reported that the effect of training is expressed faster in younger individuals than in adults. Also, Moritani and Vries (1980) reported in a study of muscle training in test subjects aged 22 to 70 years that elderly individuals are slower to express the effect of training. The results of this study support the findings of earlier studies.

One of the reasons that the effect of training is expressed faster in younger individuals than in elderly individuals is the effect of developmental growth. That is, IPS variation in this study is considered to be the result of developmental growth, which differs from the response to training. In the dynamic system model that was employed in this study, I assumed that the variation of fitness component depended only on the training and that it bordered upon the individual exponential component. As a result, there is a possibility that the developmental growth phenomenon that influences IPS toward the positive may affect the time constant of fitness component and fatigue componetnt. Therefore, when training response in junior-level athletes is examined with the dynamic system model, there is a possibility that the time constant of fitness component and fatigue componetnt may show a smaller value compared with the actual value due to the fact that developmental growth is not considered.

Also, τ_2 in Busso et al. (1991) was approximately two days, a value smaller than that obtained for the test subjects in this study. Further, in addition to the effect of age, training type and swimming ability are believed to affect τ_2. Fitz-Clarke et al. (1991) reported that $\tau_{2,}$ $k_1$and k_2 are affected by training strength at each session and the number of days elapsed from the observation starting point when compared to $\tau_{1,}$ k_1 and k_2 represent the degree of vibration amplitude of fitness component and fatigue componetnt, and it is considered that the difference in the training type was expressed in the difference of τ_2

On the other hand, in the residual error plot for this study, systematic error is not accepted in the predicted value p(t) of the dynamic system model. This result shows the validity of the dynamic system model when applied to junior-level athletes. The developmental growth phenomenon in the junior level is not included in the dynamic system model structurally; however, it reflects on the parameters of fitness component and fatigue componetnt, and it may be capable of validly estimating performance.

If it is possible to apply the dynamic system model to the athletes in the junior level as it is applied to adults, I can supply training plans that consider the individual variations of each athlete on the basis of parameters ($\tau_{1,}$ $\tau_{2,}$ k_1 and k_2) that can be estimated from the model. In particular, in the case of an athlete whose τ_1 is larger and whose τ_2 is smaller, it is considered effective to schedule large training quantities one or two days prior to a race.

That is, there is no need to change the rate of the training quantity and rest greatly in the approach to the race, and it is suggested that a good performance can be achieved. On the other hand, in the case of an athlete whose τ_1 is smaller and whose τ_2 is larger, it is considered necessary to engage in a progressive reduction of training quantity and a gradual increase in rest from two to three weeks prior to a race due to the longer lasting effect fatigue componetnt. That is a good performance can be achieved by greatly changing the rate of the training and rest. Moreover, considering information on swimming ability makes it possible to plan more detailed training. However, this study included only two test subjects, making it difficult to say that the effect of the developmental growth on the dynamic system model was adequately evaluated. In the future, it is necessary to consider the degree of influence exerted on the dynamic system model by the developmental growth phenomenon by examining a larger subject population.

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