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Original Article

The influence of strategic swimming pool facility placement on swimming performance

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Abstract:
Problem Statement: There are two methods for improving athletic performance: sports biomechanics and training environment. Although there are multifarious research reports on sports biomechanics—which allows for direct analyses for improving competitive performance—studies on quantitative assessment of training environment on competitive performance are lacking. *Approach:* We analyzed the association between the swimming competition scores achieved by each prefecture in four National Sports Festivals (71st to 74th) and the number of swimming pools present in each prefecture in Japan. The number of swimming pools was normalized for the population and area of the prefecture. *Purpose:* This study proposed to examine new parameters for improving competitive swimming performance by using statistical data in the training environment. Previous investigations have lacked this focus. *Results:* The strategic placement of pools per unit area influences performance in swimming competitions, although the pools are placed to reduce bias in the number of pools per unit population. In addition, the results quantitatively confirmed the common perception among long-time participants in swimming competitions that private indoor pools are instrumental for the successful performance of swimming competitions. School pools were also found to play a significant role. *Conclusion:* The study focused on indirectly improving athletic performance from objective data by adopting a data science approach, which has been lacking in previous investigations. Although this study only analyzed data from swimming competitions, similar analyses may be warranted for other sports competitions. The proposed method could have a significant impact on sports science from the perspective of sports policy and sports promotion.
Keywords: **Training environment, competitive swimming, competitive performance, facility management, sports policy, sports data science**

Introduction

In Japan, performance in swimming competitions is influenced by indoor swimming pools because the widespread use of indoor pools makes practice possible even during the winter season. Young athletes who practice in private indoor pools become accomplished swimmers is a common perception held by people who have long been involved in competitive swimming. In addition, populated urban areas have many private indoor pools (Japan Sports Agency, 2020) and are known to produce strong, highly competitive swimmers. Data supporting this hypothesis indicates that in the inter-prefectural National Sports Festival (NSF), the prefectures with high overall scores in swimming competitions are concentrated in two highly populated regions, namely, the Tokyo metropolitan area and the Kansai region (The 71st NSF, n.d.; The 72nd NSF, n.d.; The 73rd NSF, n.d.; The 74th NSF, n.d.). However, swimmers from prefectures in non-metropolitan areas with few indoor swimming pools have also performed well in the NSF and have become members of the Japanese national team. This has happened in a few instances and precludes the testing of this premise. Despite a relative lack of indoor swimming pools, this success is currently presumed to be linked to the swimmer's innate athletic ability.

At the outset, it is unclear why swimmers who train in private indoor pools become accomplished swimmers later, and there has been a lack of thorough investigation on this issue. Identifying the key factors involved may promote improvement in competitive swimming performance. There are two methods for improving athletic performance: sports biomechanics and training environments. An understanding of sports biomechanics, which has been the focus of conventional research (Narita et al., 2017; Sanders & Psycharakis, 2009; Takagi et al., 2015), is important for improving the performance of top swimmers. For example, da Silva et al. (2019) analyzed the reaction times of participants in the World Swimming Championships, and da Silva et al. (2020) reported a comparative validation of reaction times, swimming speeds, and partial and final times for freestyle swimmers at the Olympics. Furthermore, extensive research has been conducted on various aspects, including analyzing how the presence or absence of upper limb movement affects body velocity in the propulsion direction during the kick-start phase of competitive swimming (Hyodo & Wada, 2023), the

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investigation into which jump test, among the countermovement jump, standing long jump, or squat jump, is the most accurate predictor of swim start performance (Illera-Delgado & Gea-García, 2022), and the exploration of the impacts of land-based strength and conditioning training on competitive swimming performance (Amaro et al., 2019). Whereas the availability of training environments (e.g., nearby pools and the presence of instructors) aids beginner and mid-level swimmers. Being a beginner or a mid-level athlete is a prerequisite to becoming a top-level athlete. Hence, this study focused on improvements in training environments, which have not been previously investigated. Although there are various studies on sports environment and sports facilities (Fenton et al., 2017; Humphreys & Zhou, 2015; Iversen & Cuskelly, 2015; Kellison & Mondello, 2012; Pascual et al., 2009), to the best of our knowledge, no previous study has quantitatively assessed the influence of the training environment on competitive performance. There is data available on the total number of swimming pools and instructors in Japan and the swimming competition scores at the NSF (Japan Sports Agency, 2020; The 71st NSF, n.d.; The 72nd NSF, n.d.; The 73rd NSF, n.d.; The 74th NSF, n.d.); however, it lacks systematic organization and analyses.

Therefore, in this study, we systematically organized and analyzed the association between the number of swimming pools in each prefecture in Japan (Japan Sports Agency, 2020) and the swimming competition scores achieved by each prefecture in the NSF using a statistical approach (The 71st NSF, n.d.; The 72nd NSF, n.d.; The 73rd NSF, n.d.; The 74th NSF, n.d.). First, we quantitatively assessed the perception that populated urban areas tend to produce competitive and successful swimmers thanks to the large number of private indoor pools. Furthermore, the number of swimming pools was systematically organized by swimming pool facility types and correlated with competitive performance to determine what factors influence competitive swimming performance in private indoor pools. Finally, we quantitatively evaluated the influence of pool facility placement on competitive swimming performance. Our approach adopted a data science perspective of finding new value from the training environment (pool) data and indirectly improving competitive performance, reflecting the recent trend of data science application in sports science (Grossi, 2021; Santos-Fernandez, 2019). Thus, this study differs from the perspective of improving competitive performance through sports biomechanics.

Material & methods

First, data on the number of swimming pools in each prefecture and the results of swimming competitions at the NSF were collected. Second, the important factors for improving competitive performance were analyzed using statistical methods. Since the return of Okinawa from the United States to Japan in 1972, the NSF has included all current 47 prefectures, from the 27th NSF in Kagoshima Prefecture in 1972 (Japan Sports Association, n.d.-a) to the 74th NSF in Ibaraki Prefecture in 2019. The NSF was not held in 2020 or 2021, owing to the prevalence of COVID-19. Therefore, data from 47 prefectures were collected and analyzed.

Data on the number of swimming pools in each prefecture in Japan were collected from the portal site of official statistics of Japan (e-Stat), a web portal for Japanese government statistics (Statistics of Japan, n.d.). The swimming competition results in the NSF were obtained from the webpages listing race results of major swimming competitions in Japan by Seiko Time Creation Inc., which were provided under an agreement with the Japan Swimming Federation (Japan Swimming Federation & Seiko Time Creation Inc., n.d.). Subsequently, based on the Japan Swimming Federation's method for determining total swimming competition scores, data for each prefecture in the finals of each event were tabulated as follows: 8 points for the first place, 7 points for the second place, 6 points for the third place, 5 points for the fourth place, 4 points for the fifth place, 3 points for the sixth place, 2 points for the seventh place, and 1 point for the eighth place. In the event of a tie, the rank was shared; however, the next rank was presumed absent, and the scores were added to the next rank and divided equally between the concerned prefectures.

Results

Number of swimming pools in each prefecture

Table 1 summarizes the latest data (from the survey conducted in February 2019 and published in 2020) on the number of indoor and outdoor swimming pools sorted by prefecture, obtained from the Survey on the State of Physical Education and Sports Facilities (Japan Sports Agency, 2020). Pools intended for leisure or diving were excluded as the focus was to analyze competitive performance in swimming competitions. Table 1 includes data bars for each pool category.

Furthermore, the total number of pools in a prefecture was normalized to the population and the area of the prefecture. Tables 2 and 3 provide the number of pools per million people and per 1,000 km^2 (excluding the Northern Territories and Takeshima), respectively. For information on the population and area of each prefecture—excluding the Northern Territories and Takeshima—see Appendix.

Results of the NSF

Out of 44 of the 48 NSFs held since 1972, the host prefecture has won the Emperor's Cup (i.e., achieved the highest overall score for women's and men's competitions; Japan Sports Association, n.d.-b). The 48th NSF, among these 44 ones held in 1993, was jointly hosted by the Kagawa and Tokushima prefectures, with the former winning the Emperor's Cup. The analysis may lack credibility if based only on the results of specific NSFs, as host prefectures tend to perform better. Therefore, we examined the total swimming

competition scores in the last four NSFs: the 71st (Iwate prefecture, 2016) to the 74th (Ibaraki prefecture, 2019; Japan Swimming Federation & Seiko Time Creation Inc., n.d.). These scores are included in Table 4.

Host prefectures achieve better results; thus, their scores may present as outliers in the correlation analysis. To address this, we created a scatter plot matrix of the swimming competition scores for the four NSFs (71st to 74th). No values were markedly out-of-distribution, and hence no outliers were present (Fig. 1). Consequently, we included the data for all four NSFs in our analysis.

It was not possible to definitively determine whether the effect of the increase or decrease in the number of pools would appear in the NSF results of the same year or the consequent years. Therefore, the years for which swimming competition results should be correlated with the number of pools in 2019 were uncertain. As depicted in Fig. 1, all the resultant correlation coefficients were greater than 0.9; hence, no major difference in each year's ranking was observed. Accordingly, the swimming competition scores for the 71st to 74th NSF were smoothened using the sum of their swimming competition scores (see Table 4, column 6).

Correlation between the number of swimming pools and results of the NSF

The correlation coefficients for the number of pools per unit population (Table 2) or unit area (Table 3) and the sum of the swimming competition scores in the four NSFs (Table 4) were calculated and systematically arranged (Table 5). Notably, as a result of conducting the no-correlation test (i.e., the significance test for the correlation coefficient), for a sample size of 47 current prefectures in Japan at a significance level of 5%, a correlation coefficient greater than approximately 0.288 is considered significant.

Table 1. Number of swimming pools by prefecture and category

Prefecture	Indoor				Outdoor			
	School	University, techical college	Public facility	Private facility	School	University, techical college	Public facility	Private facility
All Prefecture	784	76	1,712	1,360	23,615	151	1,874	68
Hokkaido*	108	2	224	31	377	0	89	0
Aomori	5	0	30	13	154	1	36	1
Iwate	23	1	32	6	268	1	32	0
Miyagi	23	3	32	22	546	3	15	0
Akita	1	0	30	12	284	1	27	1
Yamagata	6	0	16	13	269	1	33	0
Fukushima	12	1	45	22	490	2	71	1
Ibaraki	11	2	48	42	530	4	33	1
Tochigi	20	0	24	28	491	4	46	2
Gunma	12	0	24	23	416	3	44	1
Saitama*	31	2	28	75	1,265	2	43	1
Chiba*	28	2	42	76	980	6	68	4
Tokyo*	134	22	120	131	1,930	17	77	0
Kanagawa*	17	3	49	114	1,093	1	110	5
Niigata	21	1	58	20	511	2	51	1
Toyama	5	0	27	14	180	2	16	0
Ishikawa	3	1	28	13	237	0	19	1
Fukui	1	0	15	7	245	1	31	0
Yamanashi	25	1	27	16	185	1	19	1
Nagano	18	2	40	23	422	1	47	1
Gifu	10	1	22	17	464	1	36	0
Shizuoka	12	0	52	40	840	4	46	14
Aichi*	27	11	69	89	1,133	10	78	1
Mie	24	0	20	22	393	3	39	3
Shiga	2	3	19	18	275	2	14	0
Kyoto	10	0	22	29	432	5	37	1
Osaka*	13	5	61	75	1,512	7	80	1
Hyogo*	18	3	61	31	898	9	27	7
Nara	6	1	12	18	273	2	23	1
Wakayama	3	0	14	9	260	2	45	0
Tottori	1	0	18	8	184	2	18	0
Shimane	1	1	18	7	145	1	26	0
Okayama	15	1	41	14	472	5	32	1
Hiroshima	8	3	37	25	578	4	74	2
Yamaguchi	6	0	19	20	424	4	39	0
Tokushima	2	0	14	11	186	2	21	0
Kagawa	7	0	19	17	193	4	9	0
Ehime	4	0	17	10	374	3	34	0
Kochi	6	0	13	5	322	3	32	1
Fukuoka*	12	1	49	85	735	8	62	0
Saga	7	0	10	12	246	1	26	0
Nagasaki	11	0	27	16	331	1	46	2
Kumamoto	20	0	28	17	517	6	21	0
Oita	10	1	38	13	372	3	30	2
Miyazaki	6	0	11	11	257	3	19	0
Kagoshima	18	2	39	16	637	1	41	2
Okinawa	21	0	23	24	289	2	12	9

Note: * denotes a prefecture with a population of 5 million or more. The bars for private indoor pools (the focus of the study) are in red, the rest are displayed in blue.

Created by editing the FY 2018 Survey on the State of Physical Education and Sports Facilities (Japan Sports Agency, 2020).

Table 2. Number of swimming pools per million people in each prefecture

Prefecture	Indoor				Outdoor			
	School	University, technical college	Public facility	Private facility	School	University, technical college	Public facility	Private facility
All Prefecture	6.2	0.6	13.5	10.8	186.8	1.2	14.8	0.5
Hokkaido*	20.4	0.4	42.4	5.9	71.3	0.0	16.8	0.0
Aomori	4.0	0.0	23.8	10.3	121.9	0.8	28.5	0.8
Iwate	18.5	0.8	25.8	4.8	216.0	0.8	25.8	0.0
Miyagi	9.9	1.3	13.8	9.5	235.8	1.3	6.5	0.0
Akita	1.0	0.0	30.6	12.2	289.5	1.0	27.5	1.0
Yamagata	5.5	0.0	14.7	11.9	246.8	0.9	30.3	0.0
Fukushima	6.4	0.5	24.1	11.8	262.9	1.1	38.1	0.5
Ibaraki	3.8	0.7	16.7	14.6	184.2	1.4	11.5	0.3
Tochigi	10.3	0.0	12.3	14.4	252.3	2.1	23.6	1.0
Gunma	6.1	0.0	12.3	11.8	213.1	1.5	22.5	0.5
Saitama*	4.2	0.3	3.8	10.2	172.6	0.3	5.9	0.1
Chiba*	4.5	0.3	6.7	12.2	156.7	1.0	10.9	0.6
Tokyo*	9.7	1.6	8.7	9.5	139.6	1.2	5.6	0.0
Kanagawa*	1.9	0.3	5.3	12.4	119.1	0.1	12.0	0.5
Niigata	9.3	0.4	25.8	8.9	227.5	0.9	22.7	0.4
Toyama	4.8	0.0	25.7	13.3	171.4	1.9	15.2	0.0
Ishikawa	2.6	0.9	24.5	11.4	207.3	0.0	16.6	0.9
Fukui	1.3	0.0	19.4	9.0	316.5	1.3	40.1	0.0
Yamanashi	30.6	1.2	33.0	19.6	226.4	1.2	23.3	1.2
Nagano	8.7	1.0	19.4	11.1	204.6	0.5	22.8	0.5
Gifu	5.0	0.5	11.0	8.5	232.3	0.5	18.0	0.0
Shizuoka	3.3	0.0	14.2	10.9	229.6	1.1	12.6	3.8
Aichi*	3.6	1.5	9.2	11.8	150.3	1.3	10.3	0.1
Mie	13.4	0.0	11.2	12.3	219.4	1.7	21.8	1.7
Shiga	1.4	2.1	13.5	12.7	194.8	1.4	9.9	0.0
Kyoto	3.9	0.0	8.5	11.2	166.7	1.9	14.3	0.4
Osaka*	1.5	0.6	6.9	8.5	171.6	0.8	9.1	0.1
Hyogo*	3.3	0.5	11.1	5.7	163.7	1.6	4.9	1.3
Nara	4.5	0.7	9.0	13.4	203.9	1.5	17.2	0.7
Wakayama	3.2	0.0	15.0	9.6	278.1	2.1	48.1	0.0
Tottori	1.8	0.0	32.1	14.3	328.6	3.6	32.1	0.0
Shimane	1.5	1.5	26.5	10.3	213.2	1.5	38.2	0.0
Okayama	7.9	0.5	21.6	7.4	248.7	2.6	16.9	0.5
Hiroshima	2.8	1.1	13.1	8.9	205.2	1.4	26.3	0.7
Yamaguchi	4.4	0.0	13.9	14.6	309.5	2.9	28.5	0.0
Tokushima	2.7	0.0	19.0	14.9	252.7	2.7	28.5	0.0
Kagawa	7.3	0.0	19.8	17.7	200.6	4.2	9.4	0.0
Ehime	3.0	0.0	12.6	7.4	276.6	2.2	25.1	0.0
Kochi	8.5	0.0	18.4	7.1	456.1	4.2	45.3	1.4
Fukuoka*	2.3	0.2	9.6	16.6	143.9	1.6	12.1	0.0
Saga	8.5	0.0	12.2	14.7	300.4	1.2	31.7	0.0
Nagasaki	8.2	0.0	20.1	11.9	246.8	0.7	34.3	1.5
Kumamoto	11.4	0.0	15.9	9.7	294.3	3.4	12.0	0.0
Oita	8.7	0.9	33.2	11.4	325.2	2.6	26.2	1.7
Miyazaki	5.6	0.0	10.2	10.2	237.7	2.8	17.6	0.0
Kagoshima	11.2	1.2	24.2	9.9	394.7	0.6	25.4	1.2
Okinawa	14.5	0.0	15.9	16.6	199.6	1.4	8.3	6.2

Note: Data extrapolated and adapted from the FY 2018 Survey on the State of Physical Education and Sports Facilities (Japan Sports Agency, 2020) and the Social Indicators by Prefecture 2020 (Ministry of Internal Affairs and Communications, 2020).

Table 3. Number of pools per 1,000 km² in each prefecture, excluding the Northern Territories and Takeshima

Prefecture	Indoor				Outdoor			
	School	University, technical college	Public facility	Private facility	School	University, technical college	Public facility	Private facility
All Prefecture	2.1	0.2	4.6	3.6	63.3	0.4	5.0	0.2
Hokkaido*	1.4	0.0	2.9	0.4	4.8	0.0	1.1	0.0
Aomori	0.5	0.0	3.1	1.3	16.0	0.1	3.7	0.1
Iwate	1.5	0.1	2.1	0.4	17.5	0.1	2.1	0.0
Miyagi	3.2	0.4	4.4	3.0	75.0	0.4	2.1	0.0
Akita	0.1	0.0	2.6	1.0	24.4	0.1	2.3	0.1
Yamagata	0.6	0.0	1.7	1.4	28.9	0.1	3.5	0.0
Fukushima	0.9	0.1	3.3	1.6	35.5	0.1	5.2	0.1
Ibaraki	1.8	0.3	7.9	6.9	86.9	0.7	5.4	0.2
Tochigi	3.1	0.0	3.7	4.4	76.6	0.6	7.2	0.3
Gunma	1.9	0.0	3.8	3.6	65.4	0.5	6.9	0.2
Saitama*	8.2	0.5	7.4	19.7	333.1	0.5	11.3	0.3
Chiba*	5.4	0.4	8.1	14.7	190.0	1.2	13.2	0.8
Tokyo*	61.1	10.0	54.7	59.7	879.7	7.7	35.1	0.0
Kanagawa*	7.0	1.2	20.3	47.2	452.4	0.4	45.5	2.1
Niigata	1.7	0.1	4.6	1.6	40.6	0.2	4.1	0.1
Toyama	1.2	0.0	6.4	3.3	42.4	0.5	3.8	0.0
Ishikawa	0.7	0.2	6.7	3.1	56.6	0.0	4.5	0.2
Fukui	0.2	0.0	3.6	1.7	58.5	0.2	7.4	0.0
Yamanashi	5.6	0.2	6.0	3.6	41.4	0.2	4.3	0.2
Nagano	1.3	0.1	2.9	1.7	31.1	0.1	3.5	0.1
Gifu	0.9	0.1	2.1	1.6	43.7	0.1	3.4	0.0
Shizuoka	1.5	0.0	6.7	5.1	108.0	0.5	5.9	1.8
Aichi*	5.2	2.1	13.3	17.2	219.0	1.9	15.1	0.2
Mie	4.2	0.0	3.5	3.8	68.1	0.5	6.8	0.5
Shiga	0.5	0.7	4.7	4.5	68.5	0.5	3.5	0.0
Kyoto	2.2	0.0	4.8	6.3	93.7	1.1	8.0	0.2
Osaka*	6.8	2.6	32.0	39.4	793.6	3.7	42.0	0.5
Hyogo*	2.1	0.4	7.3	3.7	106.9	1.1	3.2	0.8
Nara	1.6	0.3	3.3	4.9	74.0	0.5	6.2	0.3
Wakayama	0.6	0.0	3.0	1.9	55.0	0.4	9.5	0.0
Tottori	0.3	0.0	5.1	2.3	52.5	0.6	5.1	0.0
Shimane	0.1	0.1	2.7	1.0	21.6	0.1	3.9	0.0
Okayama	2.1	0.1	5.8	2.0	66.3	0.7	4.5	0.1
Hiroshima	0.9	0.4	4.4	2.9	68.2	0.5	8.7	0.2
Yamaguchi	1.0	0.0	3.1	3.3	69.4	0.7	6.4	0.0
Tokushima	0.5	0.0	3.4	2.7	44.9	0.5	5.1	0.0
Kagawa	3.7	0.0	10.1	9.1	102.8	2.1	4.8	0.0
Ehime	0.7	0.0	3.0	1.8	65.9	0.5	6.0	0.0
Kochi	0.8	0.0	1.8	0.7	45.3	0.4	4.5	0.1
Fukuoka*	2.4	0.2	9.8	17.0	147.4	1.6	12.4	0.0
Saga	2.9	0.0	4.1	4.9	100.8	0.4	10.7	0.0
Nagasaki	2.7	0.0	6.5	3.9	80.1	0.2	11.1	0.5
Kumamoto	2.7	0.0	3.8	2.3	69.8	0.8	2.8	0.0
Oita	1.6	0.2	6.0	2.1	58.7	0.5	4.7	0.3
Miyazaki	0.8	0.0	1.4	1.4	33.2	0.4	2.5	0.0
Kagoshima	2.0	0.2	4.2	1.7	69.3	0.1	4.5	0.2
Okinawa	9.2	0.0	10.1	10.5	126.7	0.9	5.3	3.9

Note: Data extrapolated and adapted from the FY 2018 Survey on the State of Physical Education and Sports Facilities (Japan Sports Agency, 2020) and the Social Indicators by Prefecture 2020 (Ministry of Internal Affairs and Communications, 2020).

Table 4. Total swimming competition scores by prefecture and their sums

Prefecture	71st NSF, 2016	72nd NSF, 2017	73rd NSF, 2018	74th NSF, 2019	Sum of the four scores
Hokkaido*	10.0	7.0	16.0	18.0	51.0
Aomori	0.0	12.0	8.0	16.0	36.0
Iwate	2.0	0.0	0.0	0.0	2.0
Miyagi	14.0	8.0	4.0	5.0	31.0
Akita	0.0	0.0	2.0	3.0	5.0
Yamagata	16.0	10.0	12.5	17.0	55.5
Fukushima	9.0	8.0	4.0	2.0	23.0
Ibaraki	17.0	31.0	38.0	32.5	118.5
Tochigi	50.5	25.0	34.5	37.0	147.0
Gunma	60.0	53.0	29.0	22.0	164.0
Saitama*	199.0	213.0	177.0	164.5	753.5
Chiba*	104.0	57.0	112.5	67.5	341.0
Tokyo*	239.5	287.0	268.5	268.0	1063.0
Kanagawa*	210.0	276.0	243.0	262.5	991.5
Niigata	49.5	26.0	57.0	38.0	170.5
Toyama	1.0	9.0	19.5	11.0	40.5
Ishikawa	20.0	19.0	18.0	19.0	76.0
Fukui	3.0	9.0	17.5	3.0	32.5
Yamanashi	17.0	18.0	14.0	3.5	52.5
Nagano	17.0	35.0	22.5	23.0	97.5
Gifu	26.0	1.0	7.0	13.0	47.0
Shizuoka	62.0	54.0	85.5	53.0	254.5
Aichi*	173.0	113.0	145.0	134.5	565.5
Mie	24.0	20.0	0.0	17.0	61.0
Shiga	14.0	23.0	4.0	22.0	63.0
Kyoto	34.0	69.0	47.0	58.0	208.0
Osaka*	141.5	158.0	144.5	197.5	641.5
Hyogo*	135.5	71.0	88.5	108.0	403.0
Nara	24.0	42.0	35.0	23.0	124.0
Wakayama	18.0	2.0	6.0	11.0	37.0
Tottori	15.0	16.0	20.0	22.0	73.0
Shimane	7.0	0.0	0.0	0.0	7.0
Okayama	24.0	28.0	37.0	30.0	119.0
Hiroshima	20.0	8.0	17.0	9.0	54.0
Yamaguchi	17.0	17.0	4.0	4.0	42.0
Tokushima	0.0	2.0	4.0	6.0	12.0
Kagawa	19.0	21.0	11.0	0.0	51.0
Ehime	25.5	61.0	10.5	16.0	113.0
Kochi	0.0	0.0	0.0	0.0	0.0
Fukuoka*	57.0	31.0	62.0	92.5	242.5
Saga	2.0	5.0	9.0	0.0	16.0
Nagasaki	0.0	7.0	3.0	4.0	14.0
Kumamoto	11.0	16.5	23.5	15.5	66.5
Oita	11.0	31.5	18.0	20.0	80.5
Miyazaki	6.0	1.0	1.0	3.0	11.0
Kagoshima	1.0	5.0	25.0	36.5	67.5
Okinawa	0.0	0.0	3.0	0.0	3.0

Note: * denotes a prefecture with a population of 5 million or more. Created by tabulating the swimming competition results from the 71st to 74th NSF (Japan Swimming Federation & Seiko Time Creation Inc., n.d.).

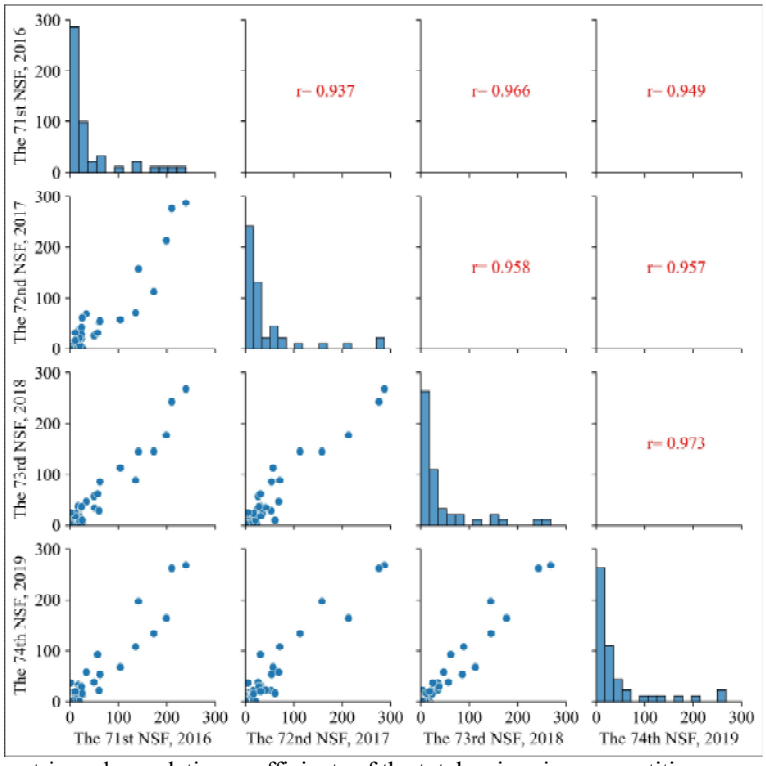

Fig. 1 Scatter plot matrix and correlation coefficients of the total swimming competition scores

Table 5. Correlation coefficients for the number of pools by category and the sum of the swimming competition scores in four National Sports Festivals (NSF)

Pool location	Correlation coefficient	
	(a) Per unit population	(b) Per unit area
Indoor / School	-0.187	0.656
Indoor / University, Technical College	0.217	0.713
Indoor / Public Facility	-0.517	0.798
Indoor / Private Facility	-0.109	0.912
Outdoor / School	-0.468	0.867
Outdoor / University, Technical College	-0.293	0.667
Outdoor / Public Facilities	-0.524	0.835
Outdoor / Private Facilities	-0.093	0.225

Discussion

The prefectures with high NSF swimming competition scores were in metropolitan areas such as Tokyo, Kanagawa, Saitama, Osaka, and Aichi (See Table 4). These prefectures have many indoor swimming pools, as indicated by the red data bars in Table 1. This is consistent with the long-held belief among people involved in swimming competitions that those who train in private indoor pools become successful swimmers. This perception was quantitatively assessed through correlation analysis, and factors that improved competitive performance were identified. As shown in Table 5, the correlation coefficients for the number of swimming pools per unit area were greater than those for the number of swimming pools per unit population without performing a significance test. Although the latter is reported (Japan Sports Agency, 2010; Japan Sports Agency, 2020) and the former is not, the data indicate that the number of swimming pools per unit area has a greater impact on swimming competitiveness than the swimming pools per unit population. Consequently, the proximity of a swimming pool to the area of residence may influence performance in swimming competitions.

Next, we focused on the number of pools per unit area. In Table 5, the correlation coefficients for private indoor facilities and outdoor school pools per unit area were the largest and second largest, respectively. The results quantitatively confirm the common perception of people involved in swimming competitions that those who train in private indoor pools become competent swimmers. Moreover, these results reveal that outdoor school pools influence competitive performance in swimming competitions, although this has not been previously recognized. Given the high correlation (0.952) between the number of outdoor school pools and indoor private pools per unit area, the presence of school pools may encourage students' interest in swimming and subsequent practice in indoor private pools. However, it is significant to note the correlation coefficient for outdoor school pools. The maintenance and management costs of school pools per unit of children become relatively higher as the number of school children and students decreases owing to declining birth rates and an aging population, making it impossible to maintain school pools. The number of outdoor school pools decreased from 28,171 in 2008 (Japan Sports Agency, 2010) to 23,615 in 2019 (Japan Sports Agency, 2020), and more than 15% of pools were discontinued during this period. Additionally, there are school pools that are neither discontinued nor in use. The actual number of such pools cannot be ascertained because of a lack of statistical data. Therefore, it is important to note that the correlation coefficients for outdoor/school pools were calculated using data that included a certain number of unused pools.

The standard deviations for the number of pools per unit population (Table 2) and per unit area (Table 3) are shown in Fig. 2. We focused particularly on private indoor facilities and outdoor school pools, as their numbers strongly correlated to the sum of the total swimming competition scores (see Table 5, column (b)). The standard deviations for these pools—normalized per unit population compared to per unit area—were clearly smaller: less than half the value. Notably, although university or technical college indoor pools have similarly small values, they are excluded from this statistical discussion because the sample size for university or technical college indoor pools is too small. This indicates that the pools are located such that no bias in their distribution per unit population exists. Therefore, the number of pools per unit area may affect the competitive performance of swimmers since pools are established fairly per unit population.

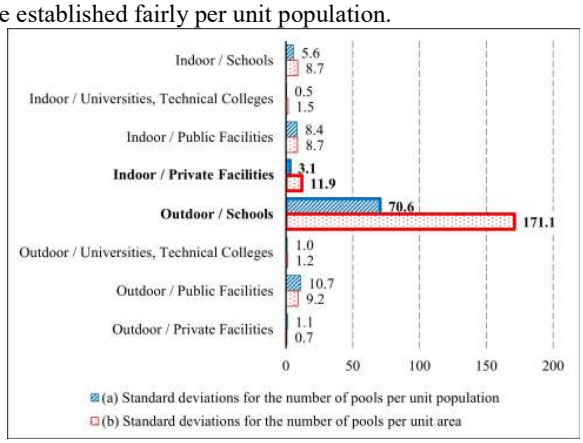

Fig. 2 Category-wise standard deviations for the normalized numbers of swimming pools

Conclusions

This study focused on factors influencing swimming performance from the perspective of the training environment rather than conventional sports biomechanics. The distribution of swimming pools throughout the prefectures in Japan was analyzed to identify factors for improving competitive performance in swimming competitions. The total number of swimming pools in each prefecture was systematically arranged and normalized for the number of people and the area of the prefecture, and a correlation analysis was performed. Although the swimming pools were placed to avoid bias in their distribution per unit population, the number of pools per unit area appears to be an important determinant of competitive performance in swimming competitions. This analysis highlights the need to focus on strategically placing pools per unit area rather than adding more pools to improve performance in swimming competitions. The importance of private indoor pools for achieving competitive performance—which has been advocated by people long involved in swimming competitions—was quantitatively confirmed through correlation analysis. Finally, the analysis also highlighted the significance of outdoor school pools. Thus, the results focus on indirectly improving athletic performance from objective data through a data science approach. The study succeeds in unfolding new parameters hitherto undiscovered in previous studies.

This study analyzed factors for promoting swimming in prefectures in Japan with low competitive performance and for popularizing competitive swimming in countries where it is not commonly practiced. Future studies may focus on regression and factor analyses using machine learning. Although this study focused on swimming competitions, similar analyses can be performed for other pool-related events, such as diving, artistic swimming, and non-swimming-related events. The results provide new knowledge to improve athletic performance not from the perspective of conventional sports biomechanics but from the perspective of sports policy and sports promotion.

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Conflicts of interest

The authors report that there are no competing interests.

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Appendix: Population and area of each prefecture

Prefecture	Population	Area (km²)
Total	126,443,000	372,971
Hokkaido*	5,286,000	78,421
Aomori	1,263,000	9,646
Iwate	1,241,000	15,275
Miyagi	2,316,000	7,282
Akita	981,000	11,638
Yamagata	1,090,000	9,323
Fukushima	1,864,000	13,784
Ibaraki	2,877,000	6,097
Tochigi	1,946,000	6,408
Gunma	1,952,000	6,362
Saitama*	7,330,000	3,798
Chiba*	6,255,000	5,158
Tokyo*	13,822,000	2,194
Kanagawa*	9,177,000	2,416
Niigata	2,246,000	12,584
Toyama	1,050,000	4,248
Ishikawa	1,143,000	4,186
Fukui	774,000	4,191
Yamanashi	817,000	4,465
Nagano	2,063,000	13,562
Gifu	1,997,000	10,621
Shizuoka	3,659,000	7,777
Aichi*	7,537,000	5,173
Mie	1,791,000	5,774
Shiga	1,412,000	4,017
Kyoto	2,591,000	4,612
Osaka*	8,813,000	1,905
Hyogo*	5,484,000	8,401
Nara	1,339,000	3,691
Wakayama	935,000	4,725
Tottori	560,000	3,507
Shimane	680,000	6,708
Okayama	1,898,000	7,114
Hiroshima	2,817,000	8,480
Yamaguchi	1,370,000	6,113
Tokushima	736,000	4,147
Kagawa	962,000	1,877
Ehime	1,352,000	5,676
Kochi	706,000	7,104
Fukuoka*	5,107,000	4,987
Saga	819,000	2,441
Nagasaki	1,341,000	4,131
Kumamoto	1,757,000	7,410
Oita	1,144,000	6,341
Miyazaki	1,081,000	7,735
Kagoshima	1,614,000	9,187
Okinawa	1,448,000	2,281

Note 1: The Northern Territories and Takeshima are not included in the area.
Note 2: * denotes a prefecture with a population of ≥5 million.
Source: Social Indicators by Prefecture 2020 (Ministry of Internal Affairs and Communications, 2020).