

Secular trends in physical fitness and performance of university track and field athletes

-  **Yukiya Matsumoto**  . Graduate School of Health and Sports Science. Juntendo University. Inzai-city, Japan.
-  **Yoshimitsu Kohmura**. Faculty of Health and Sports Science. Juntendo University. Inzai-city, Japan.
- Akira Nakamura**. Faculty of Health and Sports Science. Juntendo University. Inzai-city, Japan.
- Yuta Takanashi**. Faculty of Health and Sports Science. Juntendo University. Inzai-city, Japan.
-  **Kazuhiro Aoki**. Faculty of Health and Sports Science. Juntendo University. Inzai-city, Japan.


ABSTRACT

There are only few records of physical fitness data for athletes. This study aimed to explore the secular trends in physical fitness data of student athletes and the relationship of fitness parameters with the results of intercollegiate sports competitions. We used the physical fitness data of male students belonging to the Juntendo University Athletics Club from 1999 to 2019. The analysed parameters were height, weight, chest circumference, skinfold thickness, grip strength, vertical jump, sidestep, and sit and reach test. The ekiden results were examined in relation to data on medium- and long-distance activities with reference to the ranking. The study results suggested no difference in the skinfold thickness of the upper extremity across the events, except for throwing events. Grip strength declined gradually in sprints, hurdles, and jumping events, while it was high in throwing events. Vertical jump records declined over time in all events and remained at low levels in middle- and long-distance events. Sidestep improved among males in the general population, while it remained the same among all athletes. A relationship was found between grip strength and vertical jump, which are indices of muscle strength and power, and competitive results obtained in middle- and long-distance races.

Keywords: Performance analysis, Physical conditioning, Student athlete, Athletic performance, Grip strength, Vertical jump, Sit and reach test.

Cite this article as:

Matsumoto, Y., Kohmura, Y., Nakamura, A., Takanashi, Y., & Aoki, K. (2023). Secular trends in physical fitness and performance of university track and field athletes. *Scientific Journal of Sport and Performance*, 2(3), 381-394. <https://doi.org/10.55860/JZMZ6927>

 **Corresponding author.** Graduate School of Health and Sports Science. Juntendo University. Inzai-city, Japan.

E-mail: Sh4221014@juntendo.ac.jp

Submitted for publication June 03, 2023.

Accepted for publication June 13, 2023.

Published June 20, 2023.

[Scientific Journal of Sport and Performance](#). ISSN 2794-0586.

©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.

doi: <https://doi.org/10.55860/JZMZ6927>

INTRODUCTION

Many studies have reported the relationship between physical fitness and performance in athletics (Loturco et al., 2019; Nuzzo et al., 2008). Events such as sprint (Maćkala et al., 2015; Loturco et al., 2015), middle- or long-distance races (Castillo-Domínguez et al., 2021; Yamanaka et al., 2019), jumps (Zushi et al., 2020; Inaoka et al., 1993), throws (Bouhlef et al., 2007; Terzis et al., 2007), and decathlons (Reuter et al., 2017; Yoshioka et al., 2010) have all been considered. The results of these studies reveal a strong relationship between fitness and athletic performance, although the parameters that show the relationship differ depending on the type of test conducted and the athlete's specialty.

In general, data on people's physiques and physical fitness have been widely published, and changes in physical fitness over time, as well as standard values, are well known. However, when it comes to physical fitness data for athletes, there are few records and reports. The Juntendo University Track and Field Club is the team with the most wins in the All Japan Intercollegiate Track and Field Championships, and since 1969, Juntendo University has been conducting cross-sectional and longitudinal research on the physique, physical strength, and athletic ability of students who are continuously engaged in physical training, while conducting cumulative measurements for the purpose of accumulating data (Kohmura and Suzuki, 2018). It is rare to find physical fitness data of university students with a focus on physical education and sports, aggregated by grade and club activity, that have been collected continuously for more than 50 years. This makes the collection being done by Juntendo University a rare one.

With respect to Japanese university track and field events, ekiden and intercollegiate championships are among the most important events. The Hakone Ekiden, which is held at the beginning of the year, is particularly popular, and 10 school representatives compete in 10 sections—5 sections each in the outward (107.5km) and return (109.6km) trips. To demonstrate the best performance on the tracks and aim for overall victory, it is considered important that the top-ranking players in each event, who are the source of points, achieve good results. It is also believed that increasing the physical strength of the entire team will raise the level of competitiveness and build a foundation for aiming for victory. Hence, although track and field is an individual sport, it is also meaningful to conduct various studies from the perspective of the physical strength of athletes who belong to a team.

Therefore, in this study, using the physical fitness data of students belonging to university track and field clubs, we compared the physical fitness data of men of the same age in the general population, clarified their characteristics, and focused on ekiden. The purpose was to examine the relationship between physical fitness parameters and athletic performance. This study is expected to provide data on changes in physical strength of college track and field athletes and basic information on their characteristics, as well as clarify the relationship between physical strength and performance in major college track and field competitions. The knowledge thus acquired will be useful for evaluating the selection of players, devising daily training regimen, and considering tactics and strategies for games. In addition, since data on changes in the physical strength of university track and field athletes over time will be handled, the data can be widely used as reference materials for research in the future.

METHODS

Subjects

We used physical fitness data that were obtained from 1999 to 2019 from male students who belonged to track and field clubs. These data were collected in cumulative measurements at Juntendo University,

including statistical data that had already been compiled and published (Committee for Cumulative Records on Physical Fitness, 2000~2019).

The data are the average values for each of the four grades, and the following parameters were measured continuously for 21 years: height, weight, chest circumference, skinfold thickness (of the upper arm and scapula), grip strength, vertical jump, sidestep, and sit and reach test. Along with that, from the statistical data of the physical strength of non-athletic men aged 20 to 24 years, which were compiled by the government (e-Start), common parameters (height, weight, grip strength, sidestep, and sit and reach test), ranking of Hakone Ekiden (Hakone Ekiden official website). The scores for each block in each year's All Japan Intercollegiate Championships were extracted for analysis for the same year (Juntendo University track and field official website). In the All Japan Intercollegiate Championships, points are given according to the grades for each event, and the total score determines the overall grades of each school. In each category, 8 points are awarded for 1st place, 7 points for 2nd place, and so on, down to 1 point for 8th place. Years that were not ranked due to some factors were excluded from the data analysed. This research was conducted with the approval of the research ethics committee of the affiliated institution (approval number 2020-54).

Measurement of skinfold thickness and physical strength

Skinfold thickness

The subject takes a standing posture, and the examiner pinches the subject's skin. He double-pinches the skin deep enough to include the underlying fat but not the underlying muscle. A part 2 cm from the fingertip is measured with a meter. Measurements are taken on the right side only and recorded in mm. Two parts are measured in this way. The skinfold of the extensor surface of the upper arm over the triceps brachii, along the long axis of the arm, is pinched at the point that bisects the distance between the acromion and olecranon.

In the scapular region, the skinfold is pinched laterally, 45 degrees below the midline plane of the body at the point just below the inferior angle of the right scapula.

Grip strength

The dynamometer is held so that its pointers are facing outward. The subject stands upright, opens the legs naturally to the left and right, naturally lowers the arms, and grips the dynamometer as tightly as possible without touching his body or clothes. The measurement is repeated twice for the right and left arms alternately. The average of the best left and right records is calculated.

Vertical jump

Since the measurement method for vertical jump has changed after 2006, the methods used up until 2006 and from 2007 are explained.

Measurement method until 2006: Chalk is placed on the subject's fingertips, and he lies sideways against the wall, standing with the inner leg in contact with the line indicated by the measuring instrument and the outer leg in contact with a line 20 cm away. The hand is extended on the side of the wall as high as possible, and the zero point position of the measuring instrument is set on the tip of the middle finger. Both feet are placed outside the line 20 cm apart, and the subject jumps up as high as possible on the spot, touching the measuring instrument at the highest point.

Measurement method from 2007: A string is fixed to the measurement belt and mat. The subject stands on the mat, and the string is adjusted so that it is not loose. The height of the waist in the standing posture before jumping becomes the standard 0 cm, and the subject jumps as high as possible on the spot.

The measurements obtained with both methods are recorded in cm, and the record is taken for the one that can be performed twice.

Sidestep

A central line is drawn, and two parallel lines are drawn 100 cm on each side of the central line. The subject stands astride the central line and at the start signal, he side steps until he crosses or touches the right line, then returns to the central line and side steps until he crosses or touches the left line. This exercise is repeated for 20 seconds, and 1 point is awarded for each line crossed. The test is done twice, and the better measurement is recorded.

Sit and reach test

The subject takes a long-seated position and puts the back and buttocks against the wall. The centre of the palm is placed on the front edge of the long-sitting flexor, and the gauge is pulled forward with both hands while extending the elbows to straighten the back. Without letting go of the gauge, the subject slowly bends forward and slides the entire gauge straight ahead as far as possible. The hand is released after bending forward to the maximum. The movement distance is measured from the initial posture to the point of maximum forward bending. The movement that can be performed twice is recorded in cm.

For grip strength, sidestep, and sit and reach test, detailed precautions were taken in accordance with the Juntendo University physical fitness cumulative measurement method (Project Committee for Cumulative Records on Physique and Physical Fitness, 1997; Committee for Cumulative Records on Physical Fitness, 2000).

Statistical analysis

Yearly changes in physical fitness data for each block (sprint/hurdle, medium- or long-distance race, jumping, and throwing) and general men's physical fitness data were compared. The results of ekiden were compared with the middle- and long-distance race data, referring to the rankings. In addition, we examined the relationship between each block score in the All Japan Intercollegiate record and each physical strength parameter.

For statistical analysis, Pearson's product-moment correlation coefficient was calculated to verify the relationship between ekiden results, intercollegiate scores, and physical fitness data. The level of significance was set at less than 5%.

RESULTS

Secular trends in the physical fitness data

Figures 1–9 show the secular trends in physical fitness data, classified by event, for students belonging to university track and field clubs. Figures 1, 2, 6, 8, and 9 also show government statistics for men in the general population in Japan.

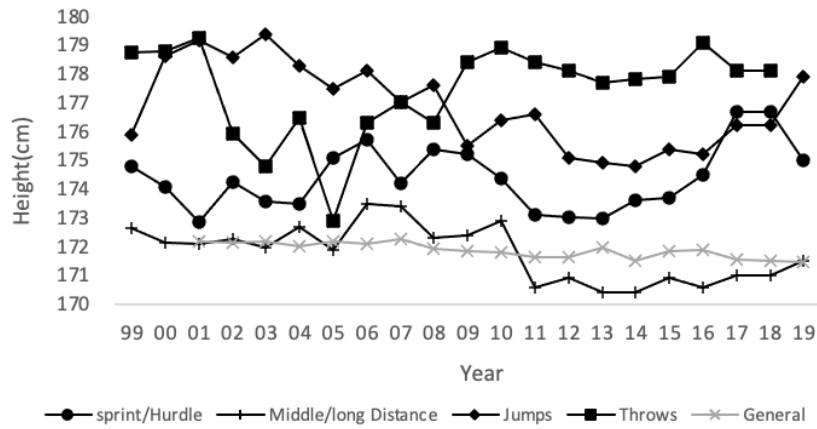


Figure 1. Secular trends in height.

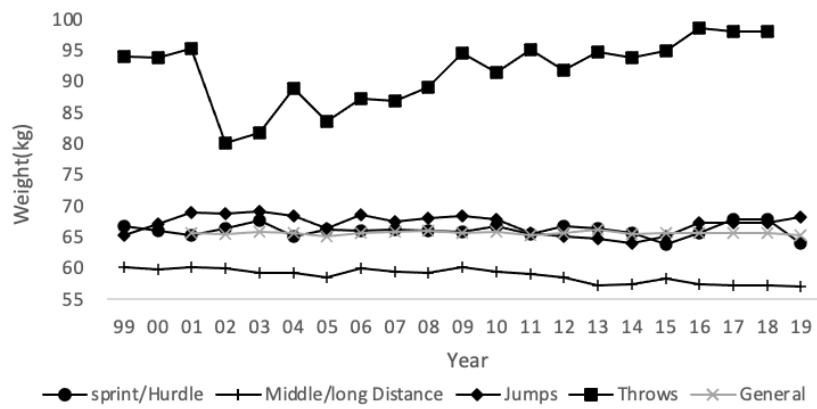


Figure 2. Secular trends in weight.

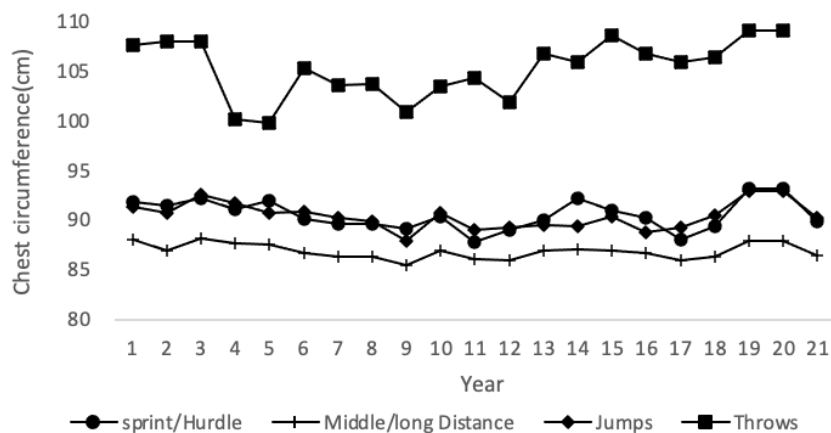


Figure 3. Secular trends in chest circumference.

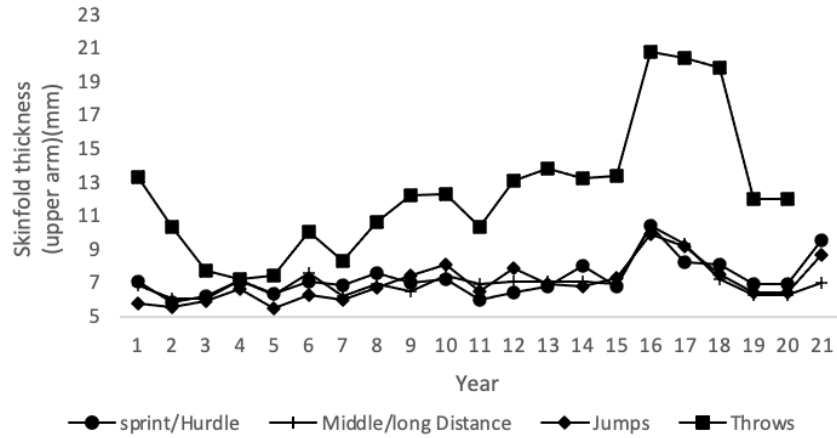


Figure 4. Secular trends in skinfold thickness (upper arm).

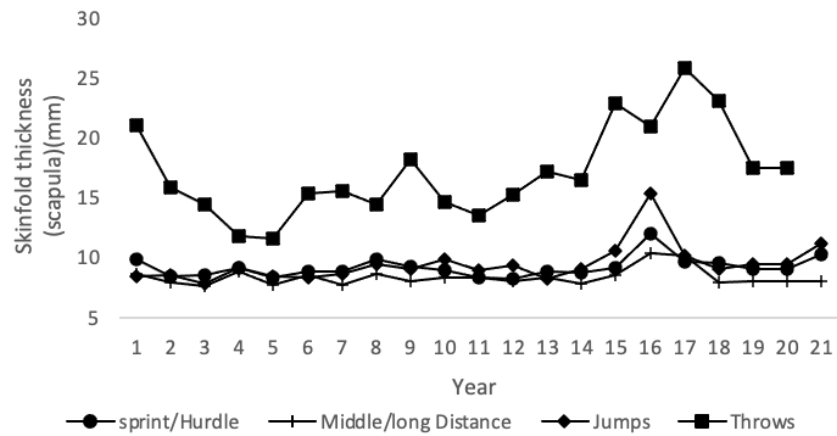


Figure 5. Secular trends in skinfold thickness (scapula).

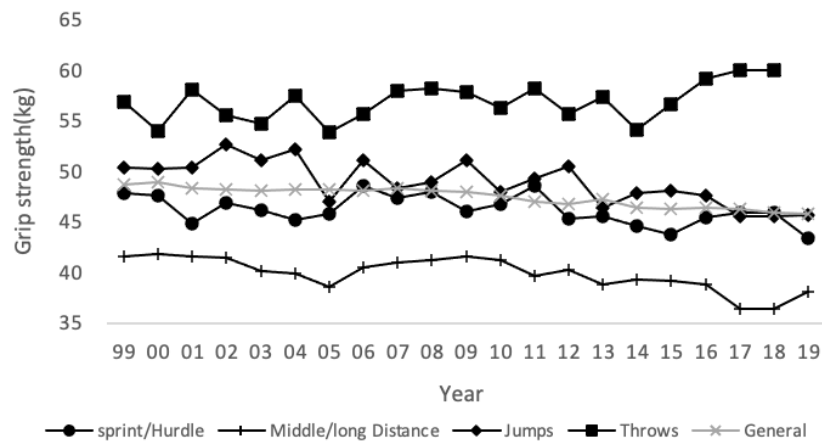


Figure 6. Secular trends in grip strength.

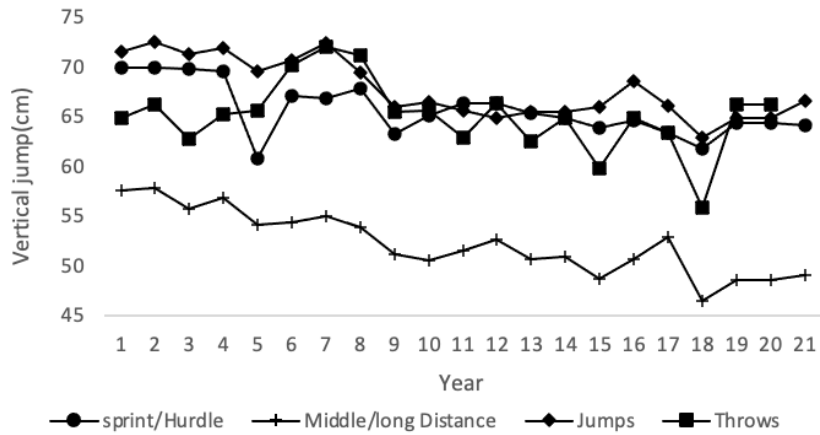


Figure 7. Secular trends in vertical jump.

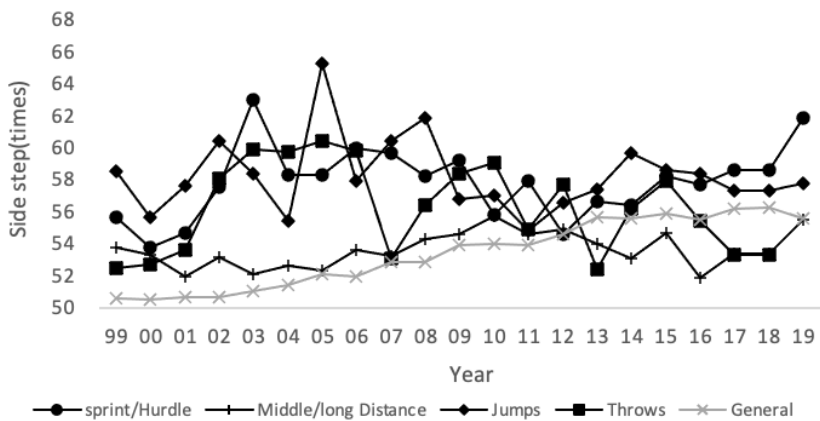


Figure 8. Secular trends inside step.

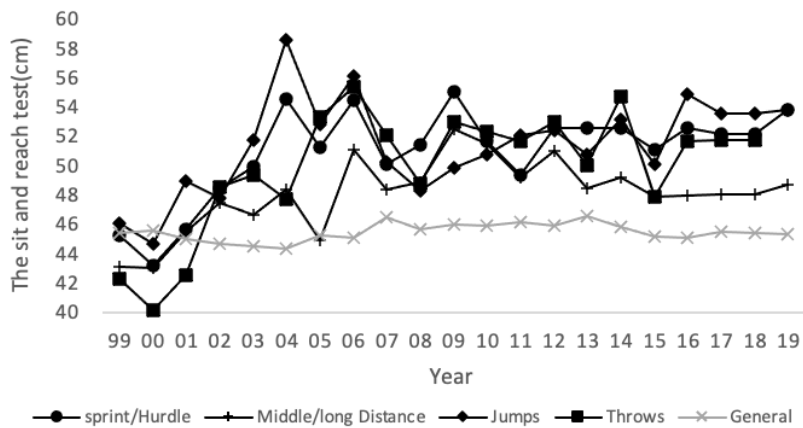


Figure 9. Secular trends in the sit and reach test.

Athletes who specialized in sprinting/hurdles, jumping, and throwing events maintained high values for height. Athletes who specialized in throwing events also had high values for body weight, chest circumference, and skinfold thickness (back of the upper arm and scapula).

Grip strength remained high for athletes who specialized in throwing events, while it remained low for athletes who specialized in medium- and long-distance races. There was a tendency for side-step records to improve over time for men in the general population, but for students of university track and field clubs, the records remained the same. Regarding the vertical jump, the records of university track and field club students tended to decline over time in all events, and the performance of athletes who specialized in middle- and long-distance events remained low. On the other hand, the sit and reach test improved over time in all events, and it remained higher among athletes than among males in the general population.

Relationship between physical fitness data, ekiden results, and all Japan intercollegiate points

Table 1 shows the ekiden rankings and intercollegiate scores for each year. In addition, Table 2 shows the correlation coefficients between the physical fitness data, ekiden ranking, and intercollegiate score.

Table 1. List of intercollegiate points and Ekiden ranking earned by event by year.

	99	0	1	2	3	4	5	6	7	8	9
Sprint/Hurdles	26	26	31	6	24	11	53	41	12	21	43
Middle/Long Distance	40	51	44	13	16	26	20	35	46	27	33
Jumps	22	21	16	32	11	14	13	20	10	18	22
Throws	25	11	16	15	13	18	13	24	8	4	17
<i>Ekiden</i>	1	2	1	2	8	5	5	4	1	DNF*1	19
	10	11	12	13	14	15	16	17	18	19	
Sprint/Hurdles	51	15	6	3	3	32	16	9	33	26	
Middle/Long Distance	12	14	7	1	14	19	20	27	20	9	
Jumps	19	12	26	34	34	3	29	24	17	15	
Throws	7	9	15	10	13	7	5	0	0	0	
<i>Ekiden</i>	DNF*2	DNF*2	7	6	16	12	6	4	11	8	

Note. DNF*1: Do not finish. DNF*2: Do not start.

Table 2. Correlation coefficients between physical fitness data, intercollegiate points, and Ekiden rankings earned by event (r).

	Sprint/Hurdles	Middle/Long distance	Jumps	Throws	Ekiden
Height	-0.36	-0.60*	-0.37	-0.15	-0.42
Weight	-0.05	-0.59*	-0.24	-0.36	-0.33
Chest circumference	-0.35	-0.05	-0.14	-0.18	-0.30
Skinfold thickness(upper arm)	-0.34	-0.33	-0.08	-0.30	-0.55*
Skinfold thickness(scapula)	-0.33	-0.20	-0.40	-0.24	-0.46
Grip strength	-0.09	-0.44*	-0.00	-0.49*	-0.25
Vertical jump	-0.23	-0.47*	-0.04	-0.30	-0.42
Sidestep	-0.12	-0.34	-0.04	-0.31	-0.36
The sit and reach test	-0.01	-0.42	-0.06	-0.19	-0.58*

Note. *: $p < .05$.

Relationship between ekiden results and physical fitness

Among medium- and long-distance runners, moderate negative correlation was observed between skinfold thickness (upper arm back, $r = -0.54$) and sit and reach test ($r = -0.58$), and ekiden results ($p < .05$).

Relationship between All Japan Intercollegiate points and physical strength

For middle- and long-distance runners, significant moderate positive correlation ($r = 0.60$, $r = 0.59$, $r = 0.44$, and $r = 0.47$, respectively) was observed between height, weight, grip strength, and vertical jump and scores.

Among throwers, significant moderate negative correlation ($r = -0.49$) was observed between grip strength and points scored.

DISCUSSION

This study analysed secular trends in the physical fitness data of athletic men in a Japanese university, comparing them with men of the same age in the general population, and explored the relationship between physical fitness and athletic performance.

Transition and comparison of physical fitness data of male students belonging to track and field clubs and men in the general population

Previous studies have suggested that athletes involved in long-distance races have smaller body weight, while those involved in throwing events weigh more (Tanaka et al., 1977). It has also been shown that athletes involved in throwing events tend to have higher fat mass and body fat percentage than those involved in other events (Hirsch et al., 2016). The results of this study are similar to these previous reports. The values of skinfold thickness were similar for athletes involved in all events except throwing events. Studies on skinfold thickness have shown that lower extremity skinfold mass is a useful predictor of running performance in several events such as 400 m, 1,500 m, and 10,000 m races (Legaz and Eston, 2005). It has been argued that skinfold thickness values do not differ among athletes who specialize in distances up to 10,000 m (Arrese et al., 2005). Based on the results of this study, it is possible that there is no difference in the skinfold thickness in the upper extremities among athletes who compete in various events, as in the case of the skinfold thickness in the lower extremities.

With respect to physical fitness parameters, grip strength, which is an evaluation index of muscle strength, the values were similar for athletes who participated in sprints/hurdles and jumping, and they showed a gradual downward trend. In addition, compared to the other three groups, athletes involved in throwing events had high grip strength values, while the medium- and long-distance runners had low values. The vertical jump, which is an evaluation index of muscle power, declined over time in all events, and it remained low in the middle- and long-distance races. The sit and reach test, which is an evaluation index of flexibility, tended to improve over time in all events although its value remained low among medium- and long-distance runners. Previous studies have shown that long-distance runners have lower muscle flexibility in the posterior lower extremities (Wang et al., 1993). The present results may thus provide longitudinal data that support previous reports. Improving flexibility is regarded as an important method of preventing injury, and in recent years, in the field of sports, guidance such as stretching methods and physical care have been actively adopted, spread, and developed by experts and trainers. The flexibility of athletes who have been trained in such settings, regardless of the sport, is higher than that of the general public, and there is a tendency to improve flexibility with such targeted training.

In a long-standing study on physique and body type (Tanaka et al., 1977), the heights of long-distance runners were smaller than the average height of students in the general population, while athletes involved in jumping and throwing events were significantly taller. The results of this study showed a similar trend. Regarding sidestep, which is an evaluation index of agility, there was a trend of improvement among males in the general population, while it levelled off among athletes in all events. From the above, it was clarified that physical strength does not necessarily improve even among college track and field athletes with sufficient exercise habits and intensity.

Relationship between competition results and physical fitness

A significant negative correlation was observed between skinfold thickness on the extensor surface of the upper arm and competition results in ekiden, in which athletes are middle- and long-distance runners with extremely low body fat mass. It has been reported that reduction in skinfold thickness in the lower extremities greatly improved running performance (Legaz and Eston, 2005). On the other hand, there are few useful reports on the relationship between skinfold thickness of the upper extremities and athletic performance. There are also results showing that both lower- and upper-extremity skinfold thickness are not related to performance (Arrese and Ostáriz, 2006). Therefore, the results of this study are contrary to those suggested previously but given the current limited number of reports on skinfold thickness in the upper extremities, it is necessary to further accumulate knowledge on this subject.

The knee joint is frequently injured regardless of running distance (Tschopp and Brunner, 2017), and it has been reported to be significantly associated with hamstring flexibility (Martinez-Cano et al., 2021). In this study, we found a moderate negative correlation between the sit and reach test, which is a popular index for evaluating hamstring flexibility (Mayorga-Vega et al., 2014), and ekiden results. This interesting finding suggests that the flexibility of the posterior leg (mainly the hamstrings) is related to the performance of athletes in the university ekiden. Considering the possibility of hamstring injury, it seems necessary to consider this relationship more carefully.

A relationship was found between grip strength and vertical jump, which are indices of muscle strength and muscle power, and scores obtained in middle- and long-distance races. Maximum oxygen uptake and economy of running are major factors that determine medium- and long-distance running performance (di Prampeco et al., 1986; Stratton et al., 2009). Intense strength training can improve running performance and maximal running speed (Skovgaard et al., 2014; Mikkola et al., 2011). Furthermore, anaerobic capacity and neuromuscular performance are enhanced, which can be expected to improve sprinting ability and economy of running in the second half of the race (Taipale et al., 2010; Jung, 2003; Blagrove et al., 2018). Based on the above, the results of this study with respect to middle- and long-distance running performance may also be related to competition results. In addition, there was a correlation between height and weight, and points scored for middle- and long-distance races, but among middle-distance and 3,000 m steeplechase runners, there was a correlation of points scored with the athletes' morphological size, which also affects the exertion of muscle strength and explosive power. A negative correlation was also observed between the performance of throwers and grip strength. Throwers require a certain level of muscle strength, but beyond that, it is conceivable that other factors such as technique are involved in competitive performance.

However, in this study, since verification was based on statistical data using the average value of each group, it is difficult to rigorously consider and interpret the relationships of the parameters with the intercollegiate results of several contestants. This is a limitation of our study, and further investigation is required in the future.

CONCLUSION

In this study, we examined the relationship between the annual changes in the physical fitness of male students belonging to a university's track and field clubs, results of ekiden, and intercollegiate scores. The main findings are as follows:

1. There was no difference in the skinfold thickness of the upper extremity among athletes involved in various events, except for the throwing events.
2. Grip strength declined gradually among athletes involved in sprints, hurdles, and jumping events, with values similar to those obtained among males in the general population. Throwers however had high grip strength. Vertical jump records tended to decline over time among all kinds of athletes, and they remained at low levels among middle- and long-distance runners. Regarding the repeated sidestep, while males in the general population tended to improve, the performance of athletes tended to remain the same.
3. Flexibility of the lower extremities (mainly hamstrings) has been shown to be related to athletic performance in university relay races, but considering the possibility of accompanying disability, it is necessary to carefully examine it in the future.
4. A relationship was found between grip strength and vertical jump, which are indices of muscle strength and muscle power, and scores obtained in middle- and long-distance races. These parameters may contribute to the achievement of excellent athletic results in college track and field athletes who specialize in middle- and long-distance races.

AUTHOR CONTRIBUTIONS

The concept for this study was proposed by Matsumoto and Kohmura. Matsumoto collected and analysed the data and prepared the first draft. Kohmura, Nakamura, Takanashi and Aoki contributed to data analyses, results interpretation, and final draft writing process.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ACKNOWLEDGMENTS

We would like to thank Editage (www.editage.com) for English language editing.

REFERENCES

- Arrese, A.L., Badillo, J.J.G., Ostáriz, E.S. (2005). Differences in skinfold thicknesses and fat distribution among top-class runners. *J Sports Med Phys Fitness.*, 45(4), 512-517.
- Arrese, A.L., Ostáriz, E.S. (2006). Skinfold thicknesses associated with distance running performance in highly trained runners. *J Sports Sci.*, 24(1), 69-76. <https://doi.org/10.1080/02640410500127751>

- Blagrove, R.C., Howatson, G., Hayes, P.R. (2018). Effects of strength training on the physiological determinants of middle- and long-distance running performance: A systematic review. *Sports Med.*, 48(5), 1117-1149. <https://doi.org/10.1007/s40279-017-0835-7>
- Bouhlef, E., Chelly, M.S., Tabka, Z., Shephard, R. (2007). Relationships between maximal anaerobic power of the arms and legs and javelin performance. *J Sports Med Phys Fitness.*, 47(2), 141-146.
- Castillo-Domínguez, A., García-Romero, J.C., Páez-Moguer, J., Ponce-García T., Medina-Alcántara, M., Alvero-Cruz, J.R. (2021). Relationship between running spatiotemporal kinematics and muscle performance in well-trained youth female athletes. A cross-sectional study. *Int J Environ Res Public Health.*, 18(16), 8869. <https://doi.org/10.3390/ijerph18168869>
- Committee for Cumulative Records on Physical Fitness. (2000). Cumulative study on physique and physical fitness of Juntendo University in 1999. *J. Health Sports Sci. Juntendo*, (4), 184-194.
- Committee for Cumulative Records on Physical Fitness. (2001). Cumulative study on physique and physical fitness of Juntendo University in 2000. *J. Health Sports Sci. Juntendo*, (5), 155-164.
- Committee for Cumulative Records on Physical Fitness. (2002). Cumulative study on physique and physical fitness of Juntendo University in 2001. *J. Health Sports Sci. Juntendo*, (6), 193-202.
- Committee for Cumulative Records on Physical Fitness. (2003). Cumulative study on physique and physical fitness of Juntendo University in 2002. *J. Health sports sci. Juntendo*, (7), 100-109.
- Committee for Cumulative Records on Physical Fitness. (2004). Cumulative study on physique and physical fitness of Juntendo University in 2003. *J. Health Sports Sci. Juntendo*, (8), 60-69.
- Committee for Cumulative Records on Physical Fitness. (2005). A cumulative study on physical fitness of Juntendo University in 2004. *J. Health Sports Sci. Juntendo*, (9), 82-91.
- Committee for Cumulative Records on Physical Fitness. (2006). Cumulative study on physical fitness of Juntendo University in 2005. *J. Health Sports Sci. Juntendo*, (10), 82-93.
- Committee for Cumulative Records on Physical Fitness. (2007). Cumulative study on physical fitness of Juntendo University in 2006. *J. Health Sports Sci. Juntendo*, (11), 110-120.
- Committee for Cumulative Records on Physical Fitness. (2008). Cumulative study on physical fitness of Juntendo University in 2007. *J. Health Sports Sci. Juntendo*, (12), 68-78.
- Committee for Cumulative Records on Physical Fitness. (2009). A cumulative study on physical fitness at Juntendo University in 2008. *J. Health Sports Sci. Juntendo*, 1(1), 118-128.
- Committee for Cumulative Records on Physical Fitness. (2010). Cumulative study on physical fitness of Juntendo University in 2009. *J. Health Sports Sci. Juntendo*, 1(Supplement), 10-20.
- Committee for Cumulative Records on Physical Fitness. (2011). Cumulative study on physical fitness of Juntendo University in 2010. *J. Health Sports Sci. Juntendo*, 2(Supplement), 23-32.
- Committee for Cumulative Records on Physical Fitness. (2012). A cumulative study on physical fitness at Juntendo University in 2011. *J. Health Sports Sci. Juntendo*, 3(Supplement), 21-31.
- Committee for Cumulative Records on Physical Fitness. (2013). A cumulative study on physical fitness at Juntendo University in 2012. *J. Health Sports Sci. Juntendo*, 4(Supplement), 11-21.
- Committee for Cumulative Records on Physical Fitness. (2014). A cumulative study on physical fitness at Juntendo University in 2013. *J. Health Sports Sci. Juntendo*, 5(Supplement), 10-26.
- Committee for Cumulative Records on Physical Fitness. (2015) A cumulative study on physical fitness at Juntendo University in 2014. *J. Health Sports Sci. Juntendo*, 6(Supplement), 17-29.
- Committee for Cumulative Records on Physical Fitness. (2016). A cumulative study on physical fitness at Juntendo University in 2015. *J. Health Sports Sci. Juntendo*, 7(Supplement), 17-28.
- Committee for Cumulative Records on Physical Fitness. (2017). A cumulative study on physical fitness at Juntendo University in 2016. *J. Health Sports Sci. Juntendo*, 8(Supplement), 13-27.
- Committee for Cumulative Records on Physical Fitness. (2018). A cumulative study on physical fitness at Juntendo University in 2017. *J. Health Sports Sci. Juntendo*, 9(Supplement), 29-41.

- Committee for Cumulative Records on Physical Fitness. (2019). A cumulative study on physical fitness at Juntendo University in 2018. *J. Health Sports Sci. Juntendo*, 10(Supplement), 1-15.
- Committee for Cumulative Records on Physical Fitness. (2020) A cumulative study on physical fitness at Juntendo University in 2019. *J. Health Sports Sci. Juntendo*, 11(Supplement), 1-26.
- Di Prampeco, P.E., Atchou, G., Brückner, J.C., Moia, C. (1986). The energetics of endurance running. *Eur J Appl Physiol.*, 55, 259-266. <https://doi.org/10.1007/BF02343797>
- Dumke, C.L., Pfaffenroth, C.M., McBride, J.M., McCauley, G.O. (2010). Relationship between muscle strength, power and stiffness and running economy in trained male runners. *Int J Sports Physiol Perform.*, 5(2), 249-261. <https://doi.org/10.1123/ijssp.5.2.249>
- Hakone Ekiden official website. Retrieved from: <https://www.hakone-ekiden.jp>
- Hirsch, K.R., Smith-Ryan, A.E., Trexler, E.T., Roelofs, E.J. (2016). Body composition and muscle characteristics of division I track and field athletes. *J Strength Cond Res.*, 30(5), 231-1238. <https://doi.org/10.1519/JSC.0000000000001203>
- Inaoka, A., Muraki Y., Kokudo, S. (1993). Characteristics of jumping events determined by control tests and relationships with the jump performances. *Jpn J Sport Methodol.*, 6(1), 41-48.
- Jung, A.P. (2003). The impact of resistance training on distance running performance. *Sports Med.*, 33(7), 539-552. <https://doi.org/10.2165/00007256-200333070-00005>
- Juntendo University track and field club official website. Retrieved from: http://www.iivanet.jp/j_trackfield/
- Kohmura, Y., Suzuki, K. (2018). The history and measurement items of cumulative study on physical fitness at Juntendo University. *Journal of Health and Sports Science Juntendo University.*, 9(2), 63-68.
- Komi, P.V., Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. *Med Sci Sports Exerc.*, 10(4), 261-265.
- Legaz, A., Eston, R. (2005). Changes in performance, skinfold thicknesses, and fat patterning after three years of intense athletic conditioning in high level runners. *Br J Sports Med.*, 39(11), 851-856. <https://doi.org/10.1136/bjism.2005.018960>
- Loturco, I., Kopal, R., Kitamura, K., Fernandes, V., Moura, N., Siqueira, F., Cal Abad, C.C., Pereira, L.A. (2019). Predictive factors of elite sprint performance: Influences of muscle mechanical properties and functional parameters. *J Strength Cond Res.*, 33(4), 974-986. <https://doi.org/10.1519/JSC.0000000000002196>
- Loturco, I., Pereira, L.A., Cal Abad, C.C., D'Angelo R.A., Fernandes, V., Kitamura K., Kopal, R., Nakamura F.Y. (2015). Vertical and horizontal jump tests are strongly associated with competitive performance in 100-m dash events. *J Strength Cond Res.*, 29(7), 1966-1971. <https://doi.org/10.1519/JSC.0000000000000849>
- Mačkala, K., Michalski, R., Čoh, M., Rausavljević, N. (2015). The relationship between 200m performance and selected anthropometric variables and motor abilities in male sprinters. *Coll Antropol.*, 39 suppl 1, 69-76.
- Martinez-Cano, J.P., Ramos-Rivera, J.C., Gómez-García, J., Casas-Barragánb, G.A., Rosalesc, M.C., Escobar-Gonzalezc, S.S. (2021). Anterior knee pain in runners after a half-marathon race. *J Clin Orthop Trauma.*, 23:101640. <https://doi.org/10.1016/j.jcot.2021.101640>
- Mayorga-Vega, D., Merino-Marban, R., Viciana J. (2014). Criterion-related validity of sit-and-reach tests for estimating hamstring and lumbar extensibility: A meta-analysis. *J Sports Sci Med.*, 13(1), 1-14. <https://doi.org/10.4100/jhse.2014.91.18>
- Mikkola, J., Vesterinen, V., Taipale, R., Capostagno, B., Häkkinen, K., Nummela A. (2011). Effect of resistance training regimens on treadmill running and neuromuscular performance in recreational endurance runners. *J Sports Sci.*, 29(13), 1359-1371. <https://doi.org/10.1080/02640414.2011.589467>

- Nakajima, R., Hirano, D., Akasaka, K., Sawada, Y., Otsudo, T. (2012). Does improvement of hamstring tightness influence knee extensor strength? *Rigakuryoho Kagaku*, 27(1), 51-54. <https://doi.org/10.1589/rika.27.51>
- Nuzzo, J.L., McBride, J.M., Cormie, P., McCaulley, G.O. (2008). Relationship between countermovement jump performance and multi joint isometric and dynamic tests of strength. *J Strength Cond Res.*, 22(3), 699-707. <https://doi.org/10.1519/JSC.0b013e31816d5eda>
- Portal site of official statistics of Japan. e-Start. Retrieved from: <https://www.e-stat.go.jp/>
- Project Committee for Cumulative Records on Physique and Physical Fitness. (1997). Cumulative study on physique and physical fitness of Juntendo University in 1996. *Journal of Health and Sports Science Juntendo University.*, (1), 113-130.
- Reuter, S., Forkel, P., Imhoff, A.B., Beitzel, K. (2017). Postural control in elite decathlon athletes. *J Sports Med Phys Fitness.*, 57(7-8), 936-941. <https://doi.org/10.23736/S0022-4707.16.06416-1>
- Skovgaard, C., Christensen, P.M., Larsen, S., Anderen, T.R., Thomassen, M., Bangsbo, J. (2014). Concurrent speed endurance and resistance training improves performance, running economy, and muscle NHE1 in moderately trained runners. *J Appl Physiol.*, 117(10), 1097-1109. <https://doi.org/10.1152/jappphysiol.01226.2013>
- Stratton, E., O'Brien, B.J., Harvey, J., Blitvich J., McNicol, A.J., Janissen, D., Paton, C., Knez, W. (2009). Treadmill velocity best predicts 5000-m run performance. *Int J Sports Med.*, 30(1), 40-45. <https://doi.org/10.1055/s-2008-1038761>
- Taipale, R.S., Mikkola, J., Nummela, A., Vesterinen, V., Capostagno, B., Walker, S., Gitonga, D., Kraemer, W.J., Häkkinen, K. (2010). Strength training in endurance runners. *Int J Sports Med.*, 31(7), 468-476. <https://doi.org/10.1055/s-0029-1243639>
- Tanaka, N., Tsujita J., Hori S., Senga, Y., Otsuki T., Yamazaki, T. (1977). Studies of physique and body shape of athletes with special reference to differences in physique among athletes of various kinds of sports. *Jpn J Phys Fitness Sports Med.*, 26, 114-123. <https://doi.org/10.7600/jspfsm1949.26.114>
- Terzis, G., Karampatsos, G., Georgiadis, G. (2007). Neuromuscular control and performance in shot-put athletes. *J Sports Med Phys Fitness.*, 47(3), 284-289.
- Tschopp, M., Brunner F. (2017). Erkrankungen und überlastungsschäden an der unteren extremität bei langstreckenläufern. *Z Rheumatol.*, 76, 443-450. <https://doi.org/10.1007/s00393-017-0276-6>
- Wang, S.S., Whitney, S.L., Burdett, R.G., Janosky, J.E. (1993). Lower extremity muscular flexibility in long distance runners. *J Orthop Sports Phys Ther.*, 17(2), 102-107. <https://doi.org/10.2519/jospt.1993.17.2.102>
- Wilk, K.E., Voight, M.L., Keirns, M.A., Gambetta, V., Andrews, J.R., Dillman, C.J. (1993). Stretch-shortening drills for the upper extremities: Theory and clinical application. *J Orthop Sports Phys Ther.*, 17(5), 225-239. <https://doi.org/10.2519/jospt.1993.17.5.225>
- Yamanaka, R., Ohnuma, H., Ando, R., Tanji, F., Ohya, T., Hagiwara, M., Suzuki, Y. (2019). Sprinting ability as an important indicator of performance in elite long-distance runners. *Int J Sports Physiol Perform.*, 15(1), 141-145. <https://doi.org/10.1123/ijsp.2019-0118>
- Yoshioka, T., Nakano, Y., Mori, K., Nakagaki, K., Nabekura, Y. (2010). Physical characteristics of Japanese decathletes evaluated from muscular strength and power. *Res Q Athl.*, (3), 26-34.
- Zushi, K., Kariyama Y., Ogata, M. (2020). Longitudinal changes in the rate of force development during single-leg press and sports performance for jumpers. *Jpn J Phys Fitness Sports Med.*, 69(5), 383-392. <https://doi.org/10.7600/jspfsm.69.38>



This work is licensed under a [Attribution-NonCommercial-ShareAlike 4.0 International](https://creativecommons.org/licenses/by-nc-sa/4.0/) (CC BY-NC-SA 4.0).