A Linear Model of Physical Ability and Its Application to the Investigation on the Growth and Development of Physical Fitness

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I. Introduction

In order to construct and/or devise methods of assessing the physical ability, such as physical fitness, motor ability and their elements, it is very rational to begin with investigating the structure of the chosen ability; that is, what components are included in it, because the chosen ability is one of human attributes of complicated and comprehensive nature. T. K, Cureton[1] (1947), the late C. H. McCloy[14] (1954), L. A. Larson[6] (1951), and so on were pioneers to have investigated the components of physical ability, such as physical fitness and motor ability, and they hypothesized them in their own unique ways. Then, Nicks and Fleishman[15] (1962) reviewed many factor analytic studies on physical fitness and motor ability which were presented up to about the beginning of the 1960s and hypothesized another type of structure of physical fitness. These hypotheses, however, have not been tested empirically and so comprehensively. In 1967, Matsuura[9] investigated the factorial structure of motor ability with the hierarchical factor model in his doctoral dissertation. These works have been done mainly with multivariate statistical analytic procedures. They have given some important suggestions on testing and assessing some abilities of comprehensive nature; e. g., motor ability in general, motor fitness, physical fitness, and the like. When we apply the factor analytic procedures to the actual data and produce several factors and interprete the extracted factors, we usually name them with the terminologies of ability area; e. g., muscular strength, cardiovascular function, cardio-respiratory endurance and so on. These factors have certain significant correlations; that is, significant factor loadings in the orthogonal solution case, with the variables of a set; items of a set, which are assumed to be validated and reliable to test and measure the chosen ability; e. g., static muscular strength test items and so on, so this factor is named static muscular strength. This is a stereotype way of interpreting the extracted factors. This means that the ability, which is defined as an extracted factor, is defined as the common area among the ability areas which are tested or measured by several test items or variables.

On the other hand, in order to measure some ability of comprehensive nature, several performance tests are very often used, because their administration is fairly easy. It can reasonably be assumed, however, that a single motor performance, even a simple one; e. g., standing broad jump as a test of leg explosive power, side step as a test of agility and so on, is done by an integrated exertion of several kinds of ability. Even for the case of measuring a simple ability; for instance, grip strength and/or back strenfth, although used very often, can not measure something which can represent the static muscular strength of total dody, It is impossible, however, to test all kinds of static muscular strength which can be exerted at all joints of body. Even if it could be supposed that it were possible, and if static muscular strength of total body could be estimated with linear combination of test results, such linear combination of variables can not stand for the static muscular strength of total body but means only the common part or domain of static muscular strength among the static muscular strength areas measured by the variables or items used. Therefore, a single variable or item can not measure the chosen ability per se in a great extent of precision and validity. Thus, the more complicated is the chosen ability, the more complicated devices are necessary to assess it.

II. Assumption

As mentioned in the preceding section, a single test item can not measure the chosen ability in pure form, because it seems rational to assume that a motor performance as a test item is done by an integrated exertion of several different abilities. Therefore, if several motor performance tests, which are validated or assumed to test the chosen ability, are administed, these test results are assumed to be highly correlated each other. Thus, if the common ability area which these items measure, can be extracted or formulated, this common ability area can be supposed as the ability which is intended to measure. This procedure, however, is not to measure the ability directly but to estimate it indirectly. As long as the test result can not represent the ability per se, this type of estimation is more reasonable to estimate it than with a single test result. This is the first assumption of this study.

Next to this assumption, a problem is how to estimate the ability with these test results. In other words, a problem is how to extract the common ability area as the chosen ability from these test results. Fortunately, we have a certain beautiful idea in a sense; that is, factor analytical procedure or component analytical procedure. If a common factor can be extracted from these test results, this factor can be interpreted as a common ability area among the abilities which contribute to a motor performance as a test item. This is a straightforward result arising from the following factor analytic assumption;

$x_i = a_i F + u_i, \; i = 1, 2, 3, \ldots\ldots n,$

where x_i stands for the i th variable or test item and it is expressed in the standard score, a_i for the i th factor loading, F for a common factor, and u_i for the uniqueness of each variable x_i.

Here x_i is hypothesized to have only one common factor, because x_i is assumed to measure the same ability. In general case, it is reasonable to assume that x_i has several common factors; $F_j, j = 1, 2, 3, \ldots\ldots m$. Then, the common factor F can be expressed in the form of linear combination of x_i in the least square sense.

Suppose that $X = (x_1, x_2, x_3, \ldots\ldots x_n)$, and $A' = (a_1, a_2, a_3, \ldots\ldots a_n)$, where n stands for number of test items or variables used. The factor analytic assumption can be expressed as follows;

$$X = AF \tag{1}$$

Then, let $F = BX$, where $B = (b_1, b_2, b_3, \ldots\ldots b_n)$, that is a coefficient vector for each x_i to estimate the factor F in the least square sense.

Then, postmultiply X' to both sides of $F = BX$,

$$FX' = BXX' \tag{2}$$

and take mathematical expectation on both sides of (2).

$$E(FX') = E(BXX')$$

$$E(FX') = B \cdot E(XX') \tag{3}$$

Here, $E(FX')$ is a correlation vector of F with $X(x_i, i=1, 2, 3, \ldots\ldots n)$, and $E(XX')$ a correlation matrix among x_i each other,
That is,

$$R_{fx} = BR_{xx} \tag{4}$$

$$R_{fx} = (r_{f1}, r_{f2}, r_{f3}, \ldots\ldots r_{fn}), \tag{5}$$

where r_{fi} stands for a correlation coefficient of F with each variable and it is equal to the factor loading in the orthogonal solution case, and R_{xx} is as follows;

$$R_{xx} = \begin{pmatrix} 1 & r_{12} & r_{13} & r_{14} \cdots\cdots\cdots r_{1n} \\ r_{21} & 1 & r_{23} & r_{24} \cdots\cdots\cdots r_{2n} \\ r_{31} & r_{32} & 1 & r_{34} \cdots\cdots\cdots r_{3n} \\ \vdots & & & \vdots \\ r_{n1} & r_{n2} & r_{n3} & r_{n4} \cdots\cdots\cdots 1 \end{pmatrix} \tag{6}$$

Therefore, postmultiply R_{xx}^{-1} to both sides of (4),

$$R_{fx}R_{xx}^{-1} = BR_{xx}R_{xx}^{-1}$$

$$R_{fx}R_{xx}^{-1} = B$$

Thus, the coefficients $B = (b_1, b_2, b_3, \ldots\ldots b_n)$ can be formulated as

$$B = R_{fx}R_{xx}^{-1} \tag{8}$$

In other words, the common factor can be estimated by $F = BX = b_1x_1 + b_2x_2 + \ldots\ldots + b_nx_n$, where x_i is the standard score of i th test result. This esimated score of F can be interpreted as a score of common ability area among the ability areas which the used test items intend to measure. Therefore, the ability, represented as F, can be expressed in the linear form of used variables; so this assumption is called "linear model of ability". Of course, it is a basic problem to test whether motor ability or physical fitness can be expressed reasonably in the linear form of test items or not. Having investigated on the history of studies on the structure of motor ability or physical fitness, however, it is found that the factor analytic theory which is based on the linearity of variables has been applied very successfully and effectively. For instance, Nicks and Fleishman[15] (1963) reviewed the factor analytic studies on physical fitness and motor ability and hypothesized the structure of physical fitness in their paper; What do physical fitness tests measure? Thus, it is reasonably justified that this assumption of linearity is applicable to estimate the physical fitness and/or motor ability with the actual test data.

III. Application of this linear model of ability to physical fitness assessment

Physical fitness is an ability of very complicated nature, as T. K. Cureton,[1] L. A. Larson,[6] Nicks and Fleisman[15] and many other researchers[2),8] hypothesized its structure which is based upon the linear combination of variables, so it is very reasonably assumed to be impossible to measure it with a single test item, so some test batteries have been formulated to estimate it actually. The method of integrating the test results, however, has never been discussed so good enough, for the basic theory or assumption of ability has not been discussed and formulated in the clear-cut way. The usual procedure has been as follows; sum of z-scores of test results or sum of raw test scores and so on. As mentioned in a section of assumption, such simple sum of test results can represent only the first centroid of test variables, so it can not represent the physical fitness or motor ability as a whole. But a single simple ability can be estimated very effectively in the form of linear combination of test results. For instance, physique items should be included as the test items in a test battery of physical fitness, and physique item usually show some significant degree of correlation with motor ability items, muscular strength items, and physical fitness test items. This means that physique should be taken into account when physical fitness is assessed. Therefore, for the first place, as many items as possible should be selected so that physical fitness as a whole could be measured as much precisely and with a great deal of validity as possible. Then, in order to investigate the interassociation between items or variables, the intercorrelations should be computed and evaluated. Then, the factor analytic procedure is applied to investigate the structure of physical fitness and to cluster the variables into the groups, each of which can be assumed to be corresponding to one common ability area of physical fitness. This process is comparable to the one which many scholars have done to find out the factorial structure of physical fitness or motor ability.

Suppose that A_i; i=1, 2, 3,......m, be the components of physical fitness, several test items should be selected to measure each A_i. Then, A_i should be represented in the form of linear combination of the selected test items. That is, A_i can be estimated as a common ability area in terms of the linear model of ability among abilities which can be represented with the test results. These common ability areas are expressed in the form of standard score, so even if the nature of ability is different, they are expressed in the same unit and scale, so all the abilities can be expressed on the same scale. This means that the different ability can be compared each other in the identical space. In other words, the one's physical fitness can be expressed in the profile and such inference as he is very strong at an ability but weak at others for strength can be made. Then this can be extended to another following application.

The ability scale axes constructed with the orthogonal factors are indepenedent each other, so any two scale axes construct the orthogonal space of two dimension. The mean vector ($\bar{F}_{1i}$, $\bar{F}_{2i}$) of the i th group can be expressed as a point in this ability space. Therefore, if such points are plotted according to age increase, the relative growth and development can be investigated such that the two kinds of ability can be considered simultaneously. This idea of relative investigation seems to have a great deal of possibility of application to many studies.

Moreover, the changing tendencies of means have been very often investigated to study some sorts of changing; e.g., growth and development. The mean value as a representative value of group is one of the effective statistic to express the central tendency of the individual distribution in a given group, but it can not show all the characteristics of group. It is very fundamental to apply the mean and degree of individual dispersion to understand the group characteristics. The application of this idea is attempted to the investigation on growth and development in the above mentioned 2 dimensional ability space.

The individual dispersion in a group can be expressed with an ellipse of a given probability in the 2 dimensional space and an ellipsoide in the n dimensional space. The equation of this ellipse is a following quadratic form of $(F-\bar{F})$; that is, for the 2 dimensional space,

$$(F-\bar{F})\Sigma^{-1}(F-\bar{F})'=\chi^2(\alpha=0.05, df=2), \quad (9)$$

where

$$(F-\bar{F})=(F_1-\bar{F}_1, F_2-\bar{F}_2)$$

$$\Sigma=\begin{pmatrix} 1 & r_{12} \\ r_{21} & 1 \end{pmatrix}, \quad r_{12}=r_{21}$$

and, for n dimensional space,

$$(F-\bar{F})\Sigma^{-1}(F-\bar{F})'=\chi^2(\alpha=0.05, df=n) \quad (10)$$

where

$$(F-\bar{F})=(F_1-\bar{F}_1, F_2-\bar{F}_2, F_3-\bar{F}_3, \ldots\ldots\ldots\ldots, F_n-\bar{F}_n),$$

$$\Sigma=\begin{pmatrix} 1 & r_{12} & r_{13} & r_{14}\cdots\cdots\cdots\cdots r_{1n} \\ r_{21} & 1 & r_{23} & \cdots\cdots\cdots\cdots r_{2n} \\ \vdots & & & \vdots \\ \vdots & & & \vdots \\ r_{n1} & r_{n2} & r_{n3} & r_{n4}\cdots\cdots\cdots\cdots 1 \end{pmatrix}, \quad r_{ij}=r_{ji}$$

and r_{ij} is a correlation coefficient of F_i with F_j in each group respectively.

$\bar{F}_i$ is a mean of F_i in each group, and $\chi^2(\alpha=0.05, df=n)\chi^2$-value at significance level of $\alpha=0.05$ with degree of freedom of n.

IV. Application of this idea to investigation on the growth and development of physical fitnes in children

The aforementioned idea on the linear model of physical ability was actually applied to the investigation on the growth and development of physical fitness of elementary children. This application will be discussed in this section.

(1). The sample size is as follows in table 1.

Table 1. Sample size

Age	7	8	9	10	11	12	TOTAL
BOY	86	65	57	45	49	12	314
GIRL	68	63	57	54	39	11	292
TOTAL	154	128	114	99	88	23	606

(2). The test items (variables used)

According to the Larson's hypothesis of physical fitness structure, the following test items were selected and used ;

I. Physique area : Linear measure—stature, lower limb length, and sitting height, Body bulk measure—chest girth, upper arm girth, thigh girth, body weight, and skinfold fat (back of upper arm and back),

II. Muscular strength area : Static muscular strength—grip strength (right and left hand), back strength, leg strength, and pull and push arm strength, Muscular endurance—chinning and leg raise, Explosive strength—standing broad jump, vertical jump, and running jump,

III. Motor fitness area : Agility and coordination—side step, zig-zag run, and shuttle run (50 m), Balance—foot balance on beam, Flexibility—trunk flexion and extension, Cardio-respiratory function—modified Harvard step test, and lung capacity,

IV. Fundamental motor skill area : Running ability—50 m dash, Throwing ability—softball throw for distance, Jumping ability—standing broad jump, and running broad jump.

These 29 test items were administered to the elementary school children sample, whose size was described in terms of age and sex in Table 1. Then, the sample consisted of the children of two elementary schools in Tsukuba Academic City, Ibaraki, and the tests were carried out in three successive days in May and June, 1977, by author and the trained examiners who were maily the graduate students majoring physical education in University of Tsukuba. The 26 items of them, however, could be performed by all subjects successfully ; that is, running broad jump, modified Harvard step test could not be performed so successfully enough by the subjects of 7 to 9 years of age as to be used to estimate the background ability, and, for side step as an agility test, the different distance between parallel lines was used for different age groups ; say, 50 cm for 6 and 7 year old children, 70 cm for 8 and 9, and 100 cm for 10 through 12. In order to investigate the developmental tendency of each ability estimated from the test items, the same ability scale should be applied to all the age groups and both sex groups. Thus, in order to construct the common ability scale, the test items, which were performed in different way according to developmental levels, were neglected from the variable sample used to estimate physical fitness.

Then, the intercorrelations were computed among variables in each each age and in each sex group respectively. These correlation coefficients were averaged through z-transformation to produce the mean correlation matrix. This correlation matrix can be thought of a correlation matrix which age difference and sex difference are partialed out, although not in a statistical sense.

Then, principal factor analysis and orthogonal rotation with Normal Varimax Criterion were applied to this mean correlation matrix. This mean correlation matrix was factored so that the common factors could be extracted as the ability scales common to all age and sex groups. Then, the following factors were extracted and interpreted;

(1). Physique,
(2). Dead weight,
(3). Static muscular strength,
(4). Dynamic muscular strength,
(5). Fundamental motor skill, and
(6). Flexibility.

The rotated factor pattern matrix is as follows in Table 2.

Table 2. The rotated factor pattern matrix

FACTOR	I	II	III	IV	V	VI	Commu.
Stature	0.53217	0.33058	0.21154	0.13462	-0.32207	0.13346	0.57663
Sitting H.	0.56287	0.31063	0.05624	0.04383	-0.30657	0.13257	0.52995
Lower L.L.	0.62749	0.43306	0.12718	0.05879	-0.34896	0.07914	0.72895
Weight	0.73690	0.45506	0.22967	0.09953	0.04047	0.09122	0.82271
S. Fat(u)	0.33233	0.88671	0.14304	0.04842	0.04580	0.09318	0.94028
S. Fat(b)	0.31030	0.89044	0.16430	0.07900	0.09606	0.09788	0.94121
Chest F.	0.71342	0.44831	0.23187	0.09384	-0.15259	0.09128	0.80414
U. Arm G.	0.71297	0.41925	0.28218	0.07734	-0.20048	0.10487	0.82089
Thigh G.	0.71451	0.31551	0.12139	0.04734	-0.15443	0.09276	0.65950
Lung C.	0.31484	0.13496	0.60792	0.98218	-0.04868	0.08113	0.50261
Grip S. (R)	0.21848	-0.21345	0.73482	0.08190	-0.14884	0.05493	0.66513
Grip S. (L)	0.20907	-0.19236	0.74082	0.11954	-0.03712	0.02357	0.64575
Back S.	0.12253	-0.13465	0.84595	0.14405	-0.19669	0.04197	0.80998
Leg S.	0.12813	-0.21306	0.81695	0.14420	-0.31961	0.07573	0.85790
Chinning	0.00575	-0.21534	0.13907	0.63831	-0.00530	-0.01020	0.47332
Vertical J.	0.29506	-0.14357	0.16359	0.41848	-0.64524	0.06946	0.74072
Push S.	0.26386	-0.21345	0.61475	0.14620	-0.17803	0.07658	0.55204
Pull S.	0.31620	-0.19365	0.77365	0.02030	-0.16035	0.07223	0.76735
Leg Endu.	0.03790	-0.21346	-0.09946	0.81104	-0.29784	0.09364	0.81216
50m Dash	-0.05598	0.10346	-0.31651	-0.44633	0.77539	-0.07611	0.92152
Softball	0.35465	0.24367	0.33063	0.07486	-0.53208	0.21809	0.63074
Trung F.	0.23299	-0.10234	0.26387	0.26561	-0.04629	0.86997	0.96392
Trunk E.	0.21571	-0.12346	0.21861	0.27341	-0.07039	0.88381	0.97039
Shuttle	-0.22471	0.24245	-0.21345	-0.43788	0.73345	-0.04071	0.88619
Balance	0.34246	-0.24365	0.10019	0.11694	-0.10537	0.24792	0.27292
Zig-zag	-0.08558	0.24246	-0.21363	-0.11884	0.80979	-0.32076	0.88452
Contribution	4.15630	3.28848	4.61566	1.96011	3.24524	1.89567	19.16146
Degree of Cont.	15.986	12.648	17.753	7.539	12.482	7.291	73.699

According to the least square procedure, the following six linear equations were obtained with considerable degree of prediction accuracy which is expressed with multiple correlation coefficient;

(1). Physique; $r=0.98990$,
$F_1=0.35466x_1+0.04390x_2+0.66565x_3$
x_1; chest girth, x_2; upper arm girth, x_3; thigh girth,

(2). Dead weight; $r=0.96134$,
$F_2=0.48641x_1+0.8641x_2$,
x_1; skinfold fat—upper arm, x_2; skinfold fat—back,

(3). Static muscular strength; $r=0.96346$,
$F_3=0.58620x_1+0.52924x_2$,
x_1; leg strength, x_2; back strength,

(4). Dynamic muscular strength, $r=0.96244$,
$F_4=0.12023x_1+0.43927x_2+0.90689x_3$,
x_1; vertical jump, x_2; chinning, x_3; leg raise,

(5). Fundamental motor skill, $r=0.96343$,
$F_5=0.30943x_1+0.43128x_2+0.57496x_3$,
x_1; 50 m dash, x_2; shuttle run, x_3; zigzag-run,

(6). Flexibility, $r=0.9887$,
$F_6=0.54124x_1+0.57367x_2$,
x_1; trunk flexion, x_2; trunk extension.

These equations are also with a great extent of practicability, because number of independent variables are rather a few for sufficient degree of prediction precision. These six equations represent the ability scales which can be used commonly in different ages and sexes, as long as age is within the age range of present study.

Then, let these constructed ability scales be applied to investigation of developmental tendency of physical fitness of the present samples. The individual data were put into these six equations of ability scale so that the ability scores could be computed for each individual. These six values represent the abilities which are taken as the sub-ability areas of physical fitness with limitation of the used variables and linear model of ability.

In order to investigate the development of these six abilities, each average of six ability scores was computed in six age groups and in both sexes, respectively. But four of them, which show some interesting tendency, will be discussed here.

(1). Investigation of growth and development of physical fitness in the ability-age space

The averages of ability scores were plotted according to age in Fig. 1 to Fig. 4. It can be thought that these curves can show the growth and development of these abilities.

The growth of physique is shown in Fig. 1 and it seems to be increasing almost linearly. The sex differences, however, are not found statistically significant, whereas the differences between the successive ages are found statistically significant in all cases for boys and for girls with exception of the cases of 7 vs. 8 and 8 vs. 9, so it can be inferred that physique growth is taking place very significantly at these ages in boys and very similar after 9 years of age in girls.

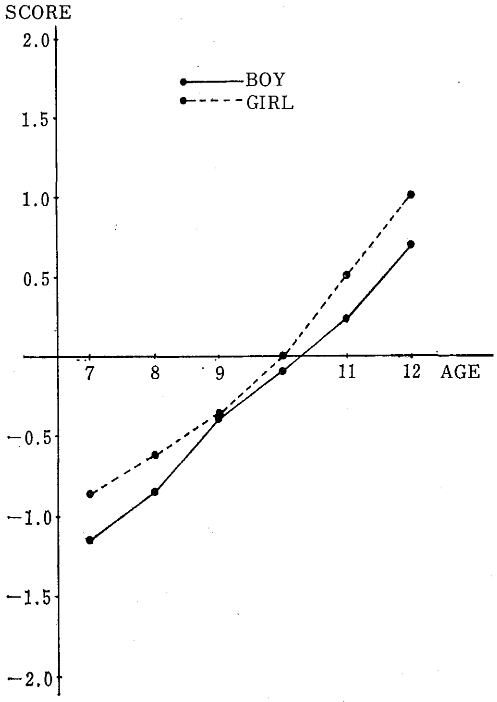

Fig. 1. Physique

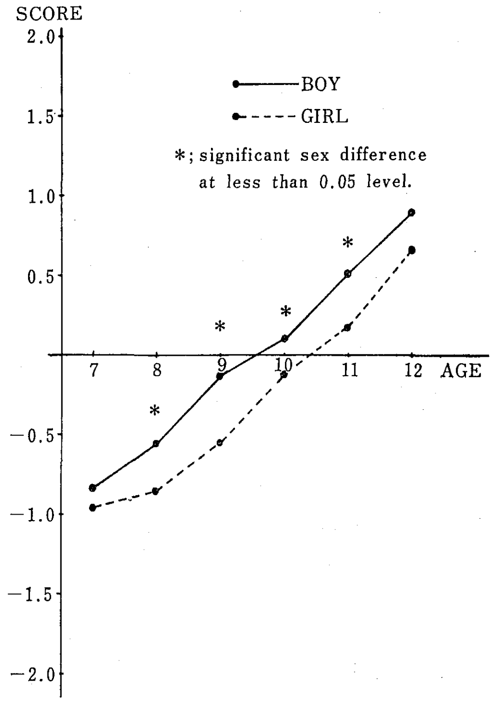

Fig. 2. Static muscular strength

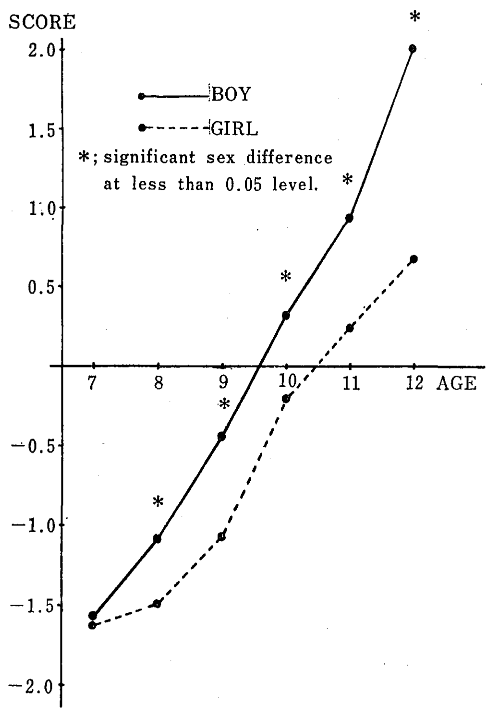

Fig. 3. Dynamic muscular strength

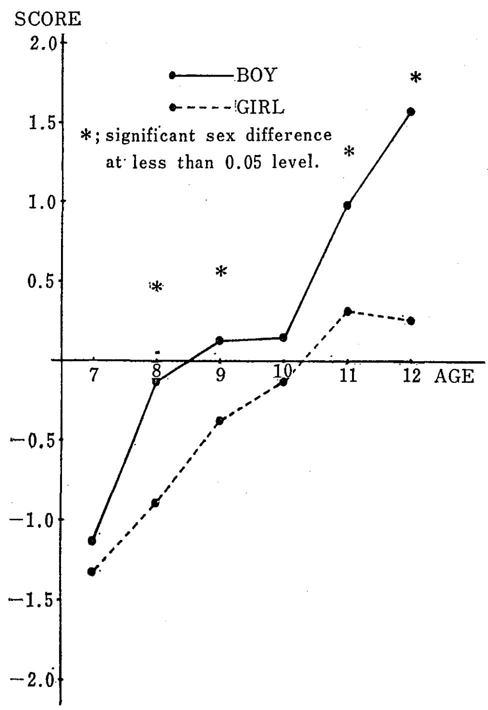

Fig. 4. Fundamental motor skill

Static muscular strength (Fig. 2) shows very definite developmental tendency in both sexes, because the mean differences between the successive ages are found statistically significant at all ages for both sexes. As for sex differences, they are found statistically significant at all ages except 7 and 12. It means that boys are stronger in static muscular strength than girls at these ages.

Dynamic muscular strength, which seems to include the explosive strength and muscular endurance, shows the most definite developmental tendency in all abilities for both sexes. Just as with static muscular strength, all the mean differences between the successive ages are found statistically significant, so that is why it can be concluded that a definite developmental tendency is found. Then, sex differences are found statistically significant at all ages except 7, and they seem to be increasing afterwards.

As for fundamental motor skill (Fig. 4), some complicated situation is shown. For boys, a great deal of increase; that is, a rapid development, is shown from 7 to 8, then such increasing tendency is degenerated up to 10, and a definite increase starts again at 10 years of age, and it seems to continue afterwards. But, for girls, a significant developmental tendency seems to continue up to 11 years of age, and some degree of degeneration seems to be taken place afterwards. As for sex difference, boys seem to be superior to girls at all ages, because the statistical test; the *t*-test, shows that the sex differences are significant at all ages except 7 and 10. It may be worth noting that the boy shows some complicated tendency of development; that is, from 8 to 10, the development seems to stop, as it were to reach at plateau, and then, development starts again at 10. Actually, at age of 9 to 10, it has been shown by many physiological studies that some hormone balance may be changed, some physiological mechanism may be changed from the younger ages, and the growth spurt may be just about to start. Therefore, that is why such plateau may occure at these ages among boys.

(2). Investigation of growth and development with ability profile

These six ability scales, which were extracted as the orthogonal factors and interpreted, are expressed in the standard score, so the intra-individual comparison of different abilities is possible. For boys, the profiles of physical fitness are shown in Fig. 5 with limitation of variables used in this study. These figures can show the developmental changes of physical fitness in terms of profile. In 7 years of age, comparatively speaking, dead weight and physique are superior to muscular strength, fundamental motor skill and flexibility, but, at eight, fundamental motor skill is shown to be nearly equal to dead weight level, and dynamic muscular strength and flexibility tend to be least developed. In other words, relative growth and developmental level is very unbalanced. The unbalance of this nature tends to decrease up to 10, but the degree of unbalance seems to increase again afterwards. This profile unbalance, however, seems to mean that weight, dynamic muscular strength and fundamental motor skill are more developed compared with growth of physique and dead weight increase. For girls, the physical fitness profile is shown in Fig. 6, and its general feature is quite different from the boy's one. At 7 and 8 the functional domain of physical fitness; e.g., dynamic muscular strength, fundamental motor skill and flexibility, is very weak or less developed for growth of physique and dead weight. The degree of profile unbalance decrease at 10; that is, only flexibility seems to be slightly superior to other abilities. In other words, girls seem to show some degree of infe-

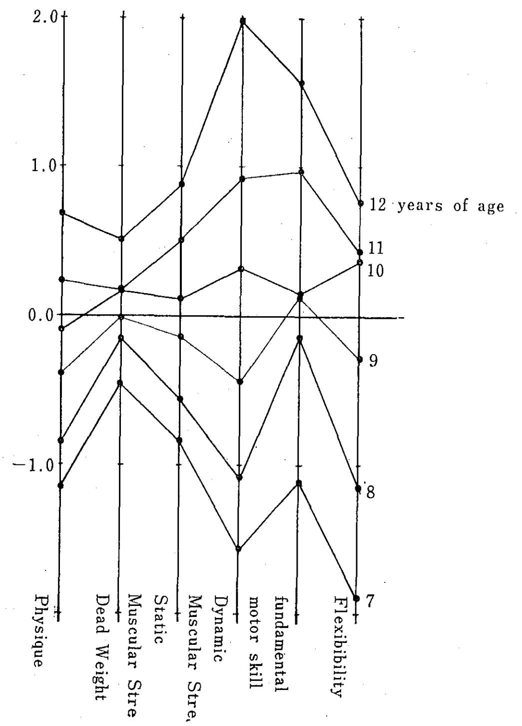

Fig. 5. Profile of physical fitness (boy)

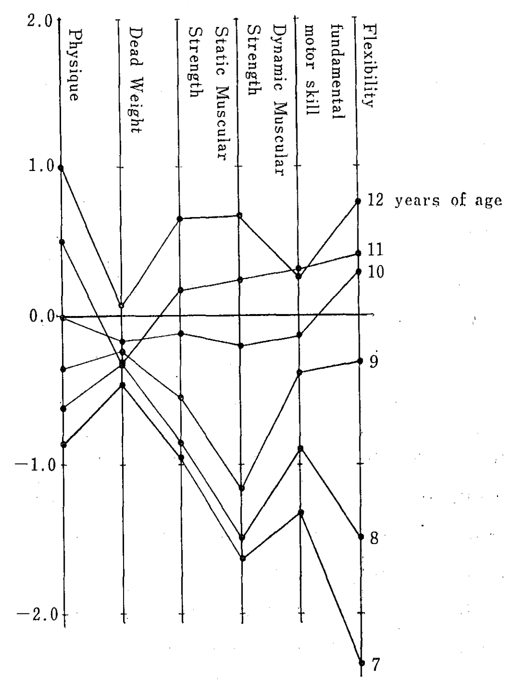

Fig. 6. Profile of physical fitness (girl)

riority in muscular strength and fundamental motor skill for growth of physique. This trend is just contrary to the boy.

(3). Relative growth and development in the 2 dimensional ability space

This six dimensional space can not be visualized. In order to visualize it, the dimensionality must be reduced to two at most. This can be done by projecting this space into the two dimensional space with any combination of two ability axes. This space can be called the ability space but not the test or variable space, because the axes are expressed with the ability scales which are expressed by the factor score formulas. In these two dimensional ability space, growth and developmental tendency can be investigated in terms of two abilities. Therefore, the growth and development of one ability can be investigated in relation to another. Then, several interesting combinations of two ability axes will be discussed below.

1). Static muscular strength vs. physique (Fig. 7)

The development of static muscular strength seems to be linear in relation to physique growth for both sexes. Comparing these tendencies with the reference straight line; $y=x$, they may be considered to be nearly parallel to it, so it can be inferred that static muscular strength develops proportionately to the growth of physique at these age levels for both sexes.

2). Dynamic muscular strength vs. physique (Fig. 8)

As Fig. 8 shows, sex difference can be shown rather clearly. For boys, the development of dynamic strength seems to be linear in relation to physique growth and, comparing with reference line, its tangent is greater, so it may be inferred that dynamic strength shows a greater

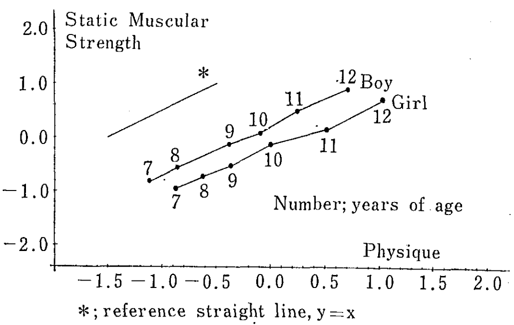

Fig. 8. Dynamic muscular strength vs.physique

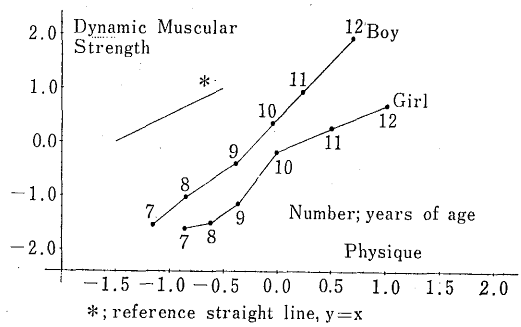

Fig. 7. Static muscular strength vs. physique

rate of development than physique at these ages. For girls, however, up to 10 years of age, the curve is concave upwards, so it may be inferred that the development of dynamic muscular strength is accerelated in relation to physique growth up to 10, but such accerelation ceases afterwards and the linear tendency, whose tangent seems to be slightly smaller than the one of reference straight line, may continue. It may mean that dynamic muscular strength shows a less rate of development than physique after 10 years of age for girls. In other words, it may be inferred that the development of dynamic muscular strength may be degenerated in relation to growth of physique in girls. This may be inferred straightforwardly from the physiological change that is thought to be taken place at these ages in girls; active operation of female hormone.

3). Fundamental motor skill vs. physique (Fig. 9)

Unlike the aforementioned two cases, a complicated tendency can be observed in boys, as Fig. 9 shows. The tendency can be observed convex upwards up to 9 years of age and any development can not be observed in relation to growth of physique between 9 and 10 in boys. Afterwards, the linear tendency of development is observed and its tangent seems to be greater than the one of reference straight line, so it may be inferred that the development of fundamental motor skill seems to be considerable in relation to the growth of physique after 10 years of age. For girls, however, the development of fundamental motor skill seems to be considerable in relation to growth of physique up to 9, and it becomes a little less up to 11, and then it seems to tend to degenerate in relation to the growth of physique. Moreover, other 11 kinds of combinations of two abilities can be investigated in the same way, but they are omitted here.

(4). Investigation on growth and development of physical fitness with consideration of the intra-group individual dispersion

If the individual difference within group is to be brought into consideration, it can be expressed by probability ellipse, as mentioned in section 3.

Let only two of them be discussed here.

1). Static muscular strength vs. physique (Fig. 10)

As discussed already in the preceding section, as long as the change of means is investigated in terms of age increase, it can be inferred that the development of static muscular strength is taken place in proportion to the growth of physiqne. Taking into account the intra-group

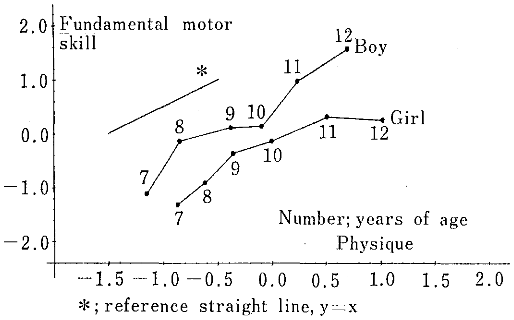

Fig. 9. Fundamental motor skill vs. physique

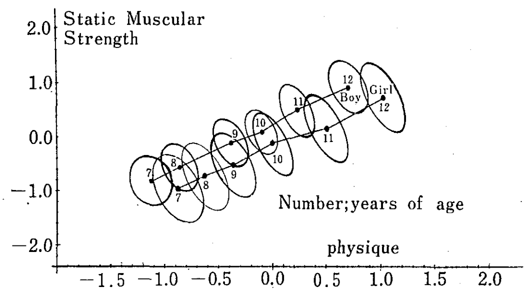

Fig. 10. Static muscular strength vs. physique

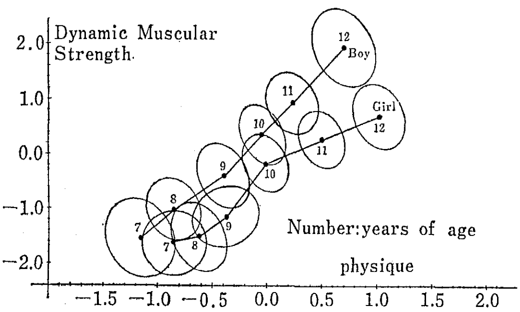

Fig. 11. Dynamic muscular strength vs. physique

individual dispersion; individual difference, which is expressed by the probability ellipse centered at means of each age group and sex group, the developmental traits which can not be inferred from the investigation of the change of means can be observed. For boys, the small overlapping area of the ellipses between 7 and 8 years of age, is found, but such area is not found afterwards. This means that the one year difference of age may produce a great deal of significant difference of ability in terms of static muscular strength and physique. In other words, the populations of over 8 years old are quite different each other in terms of static muscular strength and physique; that is, a very significant development may be taken place such that 8 year old group is quite different in ability from the 9 year old and so on.

The similar tendency may be found for girls, as Fig. 10 shows. As for sex difference, the overlapping area between boy and girl is rather large at the ages less than 10, but it decreases after 10, because a developmental tendency, such as boys be superior in strength to girls and girls superior in physique to boys, tends to appear. Taking into account the intra-group dispersion, it can be inferred that there are many boys and girls who show the same levels of growth and development in terms of static muscular strength and physique before 11 years of age, but the sex difference may become definite in terms of such two abilities of physical fitness after 11 years of age.

2). Dynamic muscular strength vs. physique (Fig. 11)

For boys, the small overlapping area of ellipse between 7 and 8 is found, as Fig. 10 shows, but it disappears afterwards. For girls, the overlapping area of considerable amount between 7 and 8, and 9, and the small even between 7 and 9 are found, and then, it disappears afterwards. Therefore, as long as the development of dynamic muscular strength is investigated in conjunction with growth of physique, it may be inferred that the girls of 7, 8, and 9 years old are with same level of ability. Compared boys with girls, the overlapping area of considerable amount are found between boys and girls before 10 years old and it tends to be less afterwards, and then, it disappears at 12 years of age, This means that the sex difference may be found very obvious after 10 years of age.

The overlapping area between boys and girls and/or between the successive age groups may show what characteristics of ability the common portion of groups that are shown by the overlapping area of ellipse may have. For example, at 11 years old, the portion of boys that may have bigger physique and weak dynamic muscular strength is overlapped with the one of girls that have smaller physique and stronger dynamic muscular strength. Thus, with taking into account the intra-group individual dispersion, more information can be produced than the growth and development curve with means plotted. The similar investigation was made on other 13 kinds of combinations of two abilities, but they are not discussed here.

V. Conclusion

This paper attempted to formulate an idea of more reasonable and precise method for assessment of physical fitness and other kinds of ability which is of complicated and comprehensive nature. Within limitation of linearity, ability and/or components of physical fitness are estimated with the test results. In other words, it is assumed that ability can be estimated more reasonably with linear combination of test results than a single test result.

Then, this idea was applied to the actual data, in order to investigate the growth and development of physical fitness of elementary children, in order to give a good evidence on the practicability and validity of this idea. Then, four kinds of investigations were attempted; that is, investigation on growth and development of physical fitness with ability score, with annual change of physical fitness profile, with annual change of position in the two dimensional ability space, and with annual change of position in the two dimensional ability space with taking into account the intra-group individul dispersion. These investigations were made on the estimated ability but not on the annual change of test results. It has been very often utilized to infere the growth and develepment of ability with the change of test results themselves. But the presented idea seems to be much more reasonable to infere the change of ability with limitation of linearity, and it can produce much more informations.

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体力の一次モデルと身体的発育発達研究への応用

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運動成就テスト (motor performance test) を用いて体力，運動能力または，その領域の能力を測定する場合，テストとしての運動の成就には，測定したい能力以外の数種の能力が程度の差こそあれ関与していると考える事は合理的であろう。また，具体的に尺度をあてがう事が出来るのは能力それ自身ではなく，能力の発揮の結果である。すなわち，運動成就テストによる能力の測定は能力の発揮の結果（顕在変数）を測定し，その結果から，その運動成就を可能にした背景的実体としての能力（潜在変数）を推定するという過程をたどると考えられる。以上の運動成就テストのモデル（これは能力の測定の一般的モデルと考えてよいと思うが，ここでは運動成就テストに限定する。）を採用する事は，能力の推定法を確立する事の必要を意味するであろう。

本論文では，以上のモデルを採用し，能力推定の操作的モデルとして，テスト結果の一次結合によって能力は推定できるとするモデルを導入した。これは，当該能力を測定すると考えられる複数種のテストの各々が測定する複数種の能力の共通領域として当該能力を抽出し，この抽出方式としてテスト結果の一次結合式を適用しようとするものである。この意味から，このモデルを体力，運動能力の一次モデルと呼ぶ事にした。このモデルの理論的導出を試み，さらに，小学校児童の体力の発育発達をこのモデルを採用して考察し，単にテスト成績の経時的変化の考察から得られる諸情報以上の結果が得られ得ること，及び，能力の発達にはより合理的である事を示した。すなわち，（1），能力の経時的変化の考察から体力の発達を検討する。（2），推定された能力は Z-得点であらわされていから，すべての能力は同一尺度で測られている事になり，個人の体力，集団の体力平均値は m 次元ベクターであらわされる。この事から，個人，集団の体力平均値をプロフィールとして考察できる事になる。（3），各種能力を相互に独立である様に抽出すれば，個人及び集団の体力平均値は m 次元直交能力空間の点であらわせ得る。この点の経時的変化の考察から総合的に体力の発達が検討できる。もし，2種の能力軸をとりあげれば，2次元直交能力空間で可視的に体力発達を検討できる。これはまた相対発達の考察になる。（4），単に平均値の経時的変化の考察より，各年令集団の体力の個人差を考慮しながら，発達を考察する事のほうがより発達現象に忠実な考察である。この個人差は m 次元空間では任意の確率に対応する m 次元楕円体であらわされる。すなわち，2次元直交能力空間（能力平面）では各年令集団の平均値を中心とする楕円である。したがって，これらの楕円の経時的変化の考察から発育発達現象により忠実な考察が可能になる。

以上の4種の方法を適用して体力の発達を考察し，体力・運動能力の一次モデルの適切性を示した。