BALANCE AND MUSCULAR STRENGTH IN NORMAL CHILDREN AGED 9-12 YEARS

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The purposes of this study were two fold. The first was to determine the effects of several independent variables on balance, and also on two muscular strength (dynamic and static) measurements respectively. The second purpose was to examine the relationship among the balance and the muscular strengths. Ninety-nine healthy children (58 boys and 41 girls) ranging in age from 9.6 to 12.7 years participated in this study. The subjects were selected from the 4th, 5th and 6th grades of an elementary school in Kaohsiung City. To assess balance, children were administered subtest 2 of Bruininks Oseretsky Test of Motor Proficiency (BOTMP). Dynamic strength was measured with the subtest 4 of the BOTMP. Static strength was measured quantitatively by "semi-squat two-hand lift". The Force Evaluation and Testing System was used for this testing. Height and weight measurements were obtained on each subject. The independent effects of variables on balance score and the two muscular strengths were assessed by stepwise multiple-regression analysis. The results revealed weight and dynamic strength were the effective predictors on estimating balance score. Gender and weight were found as important variables contributing in static load, whereas gender, weight, height and balance score were selected for significantly predicting dynamic strength score. Spearman correlation analysis revealed significant positive correlations between balance and dynamic strength and also between dynamic strength and static strength. The correlation analysis also showed a significant negative correlation between balance and static strength. Detailed implications of the results in the present study are discussed.

Key words: balance, muscular strength, developing children

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Balance is an important agent that provides a background for children to develop and achieve motor functions. In developing infants, the ability of balance enables them to become successfully mobile[1]. After infancy (from 2 to 12 years), good balance control is still very important for children to acquire advanced motor skills, such as jumping, throwing and catching[2]. However, recent studies of movements in children[3-5] find that balance contributes as an effective predictor of motor skill development only in very early childhood. We believe that additional factors may cause the inconsistency of balance performance during the period of development. Some investigators[6,7] have found that complex interactions of several factors affect the performances of balance in elder children. Besides balance, another agent also important to development of motor function is muscular strength[8]. Information on strength for infants and preschool children is not very extensive. It is believed that muscular strength increases gradually from early infancy. Thus, the variable of age is a determinant factor associating to muscular strength. Body height and weight, as well as age, have been widely investigated and found as the effective predictors of muscular strength[9-11]. The effects of body height and weight on strength are modulated by the variable of

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gender.

Due to the fact that in developing children alterations related to continuing growth increase the tendency to vary in balance performance, to identify the multifarious variables contributing to balance would be particularly important for pediatric therapists to recognize the underlying determinant factors. In addition, the relationship between balance and muscular strength in children and their mutual effects on each other are also very important. However, most of the related articles[12,13] are mainly on adults instead of children. In this study, we intended to investigate some specific anthropometric variables, which would relate to the development and exertion of balance and muscular strength in the pediatric population.

The purposes of this study were two fold. The first was to determine the effects of several independent variables on balance, and also on two muscular strengths. The second purpose was to examine the relationships among the measured balance and the muscular strengths.

MATERIALS AND METHODS

Subjects

A random sample was obtained from the fourth, fifth and sixth grades of an elementary school in Kaohsiung City. Ninety-nine of a total number of 1520 children (58 boys and 41 girls) ranging in age from 9.6 to 12.7 years (X=11.2 years) participated in this study. All the children had be healthy in musculoskeletal system and had no significant episodes of orthopedic injury. The president and class teachers of the school permitted this study in the 99 children.

Procedures

The balance and muscular strengths of each subject was measured individually. All the measurements were done in a quiet experimental room. Before testing, the measuring procedures were explained clearly to the children.

To assess balance, subjects were administered subtest 2 of Bruininks Oseretsky Test of Motor Proficiency (BOTMP)[14]. BOTMP was developed for assessing the motor functions of children from 4.5 to 14.5 years of age with normal or retarded development[3,4,15]. One of the subtests in the BOTMP, subtest 2, is specific to assessing balance. Subtest 2 consists of 8 testing items. Three items assess static balance by requiring the subject to maintain balance while standing on one leg. Five items assess performance balance by requiring the subject to maintain balance while executing various walking movements. All subjects performed the tasks in shoes.

To measure muscular strength, two kinds of strength, dynamic strength and static strength were evaluated. Dynamic strength was measured with the subtest 4 of the BOTMP. Subtest 4 consists of 3 items, which includes standing broad jump, sit-ups in 20 seconds and push-ups in 20 seconds. It can be used to assess the combination of arm and shoulder strength, abdominal strength and leg strength[14]. Before starting the test, subjects were instructed individually to perform the movements 1-2 times. During the test, a 3-minute resting period was provided after each set of test items.

The other strength measurement was static strength, which was characterized quantitatively by "semi-squat two-hand lift". During performing the squat-lift static movement, erector spine, arm and leg musculature would be recruited[16,17]. Therefore, static lifting strength can be used to predict strength capabilities[18]. The Force Evaluation and Testing System (FET 5000, Hoggan Health Industries Inc.) was used for this testing. This systematic device consists of 3 major elements. The first one is an electronic force transducer attached by a handlebar. The second one is a digital information processor, which is designed for monitoring and converting force signals. The third element is a host computer that displays and stores the data. The subjects were instructed to stand on a platform with flexed knees and straight back. They held the handlebar with two hands. The standard position was that the location of the extended arms was vertically superior to the ankles. Before the test, children were allowed 1-2 warm up repetitions, followed by a 30-seconds rest interval. Subjects were then asked to demonstrate 4 trials of maximal sustained voluntary exertions in the vertical direction by pulling on the static handlebar. Each trial was maintained for 2-4 seconds. The peak values during the period of each exertion were recorded and displayed on the computer. A resting period of 4-5 min was provided between exertions. The mean of the two highest values in the 4 exertions was calculated as the static load in pounds.

The testing orders of the balance and strength measurements were randomly arranged.

Height and weight measurements were obtained on each subject. All the measurements were obtained by two experienced physical therapists who had more than 6 years of clinical experience. One assessed balance, and the other exhibited the strength measurements.

Data analysis

During administering subtest 2 and subtest 4, the raw score of each item was recorded and then converted into point score. Both measurements were scored on the basis of the subject's best performance, with 3 trials allowed to attain any score. By adding all the point scores within each subtest, 'balance total score' (balance score) and 'strength total score' (strength score) were obtained respectively for each child.

Descriptive statistics, including means and standard deviations, were calculated respectively for both genders and the separated grades on measures of age, height, weight, balance and strength total scores, and static strength load. The given data in gender groups were analyzed by independent t-test. Two-way ANOVA was used to examine the main and interactive effects of gender and grade differences on dependent variables of balance and two strength measurements respectively.

In order to identify the most important associated determinants, the independent effects of age, gender, height, weight and muscular strengths on balance score were assessed by stepwise multiple-regression analysis. Stepwise multiple regression was also employed for examining the effects of age, gender, height, weight and balance score on the strength score and static load respectively.

Spearman correlation coefficient was used to assess the relationships among balance score, strength score and the static load. An alpha level of 0.05 was adopted for all tests.

RESULTS

Physical data for the subjects

Means and standard deviations of age, height, weight, balance score, strength score and static load in both genders and in the three grades are summarized in Table 1 and Table 2 respec-

Table 1. Means and standard deviations of the measured variables in genders (N=99)

	Gender		
	Boys (n=58)	Girls (n=41)	p value
Age (year)	11.5 ± 0.9	11.0 ± 0.9	0.111
Height (cm)	150.0 ± 10.7	146.3 ± 9.3	0.068
Weight (kg)	44.0 ± 15.0	38.7 ± 7.5	0.023 *
Balance score	22.8 ± 4.1	23.5 ± 3.3	0.608
Strength score	18.9 ± 2.6	16.0 ± 3.6	0.000 *
Static load (pound)	155.4 ± 55.1	120.1 ± 36.4	0.000 *

*t-test, $p<0.05$

Table 2. The means and standard deviations of the measured variables in the three grades (N=99)

	Grades			
	4 (n=32)	5 (n=37)	6 (n=30)	p value
Age (years)	10.1 ± 0.3*	11.4 ± 0.4**	12.1 ± 0.3***	0.000
Height (cm)	141.0 ± 7.6*	150.8 ± 10.1	153.7 ± 8.3***	0.000
Weight (kg)	35.9 ± 8.6*	44.3 ± 16.2	45.1 ± 9.1***	0.005
Balance score	23.2 ± 2.7	23.0 ± 4.2	23.0 ± 4.3	0.963
Strength score	16.8 ± 3.6*	17.4 ± 3.1	19.0 ± 3.1	0.032
Static load (pound)	122.5 ± 38.3	150.1 ± 61.8	148.6 ± 44.4	0.047

Two-way ANOVA, $p<0.05$, significant difference between: * gr.4 and gr.6 **gr.4 and gr.5, ***gr.5 and gr.6

tively. It can be noted from Table 1 that boys were significantly heavier and stronger than girls. No significant difference was found between genders in age, height or balance score.

In Table 2, significant differences were found in age among grades. As would be expected, ages of the students increase as they progress from lower grade to higher grade. In addition, both height and weight were significantly different between grade 6 and the two lower grades respectively. Concerning the balance and both strengths, significant difference was only found in strength score between grade 4 and grade 6.

Results of two-way ANOVA revealed no significant overall interactive effect of gender and grade differences on balance score (F=.51, p=.60), strength score (F=.58, p=.56) and static load (F=.04, p=.96). Therefore, gender and grade groups were pooled for the subsequent analysis.

Estimating balance score

Tables 3 showed the results of regression analysis of independent variables on estimating balance score. Age, gender, height and static load had minimal effect, whereas weight (which contributed negatively) and strength score (which contributed positively) were the significant predictors contributing to balance score.

Estimating strength score and static load

To estimate to what extent the result in strength score (dependent variable) could be explained by independent variables age, height, weight and balance score, results of regression analysis revealed age and balance score contributed significantly in strength score (Table 4). When gender was also included as an independent variable for this analysis, all of the independent variables were selected except age as significant predictors on estimating strength score.

For estimating static load by age, height, weight and balance score, multiple regression selected weight as the only significant predictor. When gender was also included for this analysis, weight and gender were selected simultaneously as the variables offering the strongest explanation of static load (Table 5).

Correlation

Table 6 shows the three correlations ranged

Table 3. Multiple-regression analysis for estimating balance total score by independent variables (N=99)

	R^2	F	Independent variables					
			Gender[a]	Age	Height	Weight	Static load	Strength score
	.33	23.5*						
b			.08	.07	-.09	-.16	.05	.20
beta			.08	.07	-.13	-.54*	.05	.18 *

* t-ratio, p<0.05; F, p<0.05.
[a] 1=boy, 2=girl

Table 4. Multiple-regression analysis for estimating strength total score (dynamic muscular strength) by independent variables (N=99)

	R^2	F	Independent variables				
			Gender[a]	Age	Height	Weight	Balance score
Gender excluded	.11	5.8*					
b				.09	.19	-.00	.19
beta				.28*	.22	-.01	.25*
Gender included	.35	12.6*					
b			-3.00	.07	.19	-.12	.22
beta			-.44*	.08	.58*	-.44*	.25*

*t-ratio, p<0.05; F, p<0.05.
[a]1=boy, 2=girl

Table 5. Multiple-regression analysis for estimating static load by independent variables (N=99)

	R^2	F	Independent variables				
			Gender[a]	Age	Height	Weight	Balance score
Gender excluded	.41	66.4*					
b				.05	.12	2.60	.13
beta				.04	.16	.64*	.12
Gender included	.45	39.7*					
b			-22.60	.02	.12	2.40	.13
beta			-.22*	.02	.15	.59*	.11

*t-ratio, $p<0.05$; F, $p<0.05$.
[a] 1=boy, 2=girl

Table 6. Spearman correlation coefficient of balance total score (Balance score), strength total score (Strength score) and static strength load (Static load)

	Strength score	Static load
Balance score	.226*	-.241*
Strength score		.271**

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

from -0.24 to 0.27; two correlations were significant at $p<0.05$ and one correlation was significant at $p<0.01$. Strength score positively correlated with both balance score and static load respectively, while balance score negatively correlated with static load.

DISCUSSION

Balance

Table 1 and 2 display the characteristics of the 99 subjects. Unlike the findings in previous studies[3,4], boys did not perform better than girls in the balance test. Generally speaking, during childhood, balance proficiency improves with age. However, from Table 2, we did not find an increase in the balance score at successive grades. Moreover, using multiple-regression analysis, gender and grade were not selected as significantly contributing to balance score. Therefore, our data indicated that gender and age may not necessarily be the decisive factors associating to balance performance in children aged 9-12 years.

From the results of regression analysis, weight explained 30% of variance in estimating balance score. The regression coefficient of weight associating to balance score was 0.55 (Table 3). This result represented that balance test used in this study was sensitive to the subjects' body weight instead of body height. In the study of Newcomer *et al.*[19], authors had suggested that the delay between peak strength increase and peak height increase was thought to be attributable to the time it takes to coordinate the muscle to work efficiently. Based on this, we judged that the poor performance in balance test associated with high body weight is thought to the possible reason that good balances control of perturbed body lags behind the faster body weight growth. Longitudinal studies should be needed to examine the long-term relationships between balance and body size during childhood.

Another noteworthy variable affecting the variance in balance score was muscular strength. Few researches have been published on the static and dynamic muscular strengths, which affect balance performance in children. The findings from this study implied that the balance test was sensitive to dynamic strength, but not to static strength. We proposed the strong association between balance and dynamic strength reflects that specific interactive effects exist between them. Therapists should recognize the importance of strength, especially dynamic muscular strength, when they evaluate balance function in children aged 9-12 years.

Strength

As the same results of past studies, in our study, there was a significant gender difference in favor of boys in strength measurements (Table 1). We supposed gender was an important factor in predicting muscular strength. Therefore, we intended to compare the different variances in the strength measurements by excluding and including the gender variable for regression analysis. As shown in Table 4 and 5, we could conclude that gender was a strong predictor for influencing the variance in both strength score and static load in children aged 9-12 years.

In the previous studies[10,20], body size or body dimension was described as an effective predictor of performance in strength tests. Our study revealed body weight was obviously more important than height in predicting muscular strength (Table 4 and 5). We were interested in noting that weight contributed significantly to strength score negatively, whereas it contributed to static load positively. The question is why the subjects with higher weight were less likely to gain strength score, but were more likely to gain static load. One possible explanation was that stabilization of the body position would affect the performances of strength exertion. During static load measurement, all the subjects maintained at a quite stable semi-squat position. When dynamic strength was measured, the subjects with higher body weight found it harder to gain good body balance during dynamic movement. We suggest good body balance control is important, which can provide adequate stability for our subjects to exert their muscle force effectively. The findings in regression analyses provided one indirect support for this assumption. From Table 3, weight was found as an effective predictor in balance score. At the same time, from Tables 4 and 5, balance score contributed significantly to strength score but not to static load. These results implied that weight affects the performance of strength exertion indirectly via directly influencing body balance control during strength exertion.

As in the above discussion, we suggested balance is important for influencing the performance of muscular strength. However, from this study, we could not exactly determine the cause-effect relationship between balance and strengths. From the results of correlation tests (Table 6), it is interesting to note that balance score was positively correlated to strength score, whereas it was negatively correlated to static load. We proposed this contrast in the result of these two correlations might be attributable to the different properties in dynamic strength and static strength. We could note that, as shown in Tables 4 and 5, there were different accounts in variance of independent variables when estimating the dynamic strength and static strength. Some authors[18,21] found variables used to estimate dynamic strength capability do not have accuracy to predict static strength. The results of our study are in agreement with these previous findings.

In the previous studies, static (isometric) lift strength measurement is popular and reliable in adult subjects[18,22,23], but not specifically in children. This study was the first one to use the FET for measuring static lift strength in children. Further studies could be done to test the validity and reliability of FET for the pediatric population.

In summary, this study showed the balance, dynamic strength and static load measurements in children aged 9-12 years. The results of multiple regression analysis revealed weight and dynamic strength were the effective predictors on estimating balance. Gender and weight were found as important variables contributing in static load, whereas gender, weight, height and balance score were selected for significantly predicting dynamic strength score. The results of correlation analysis revealed there were significant positive correlations between balance and dynamic strength and also between dynamic strength and static strength. The results also showed a significant negative correlation between balance and static strength.

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9到12歲正常兒童的平衡與肌力之相關研究

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本研究的目的爲，第一、分析數項獨立自變數對平衡能力及肌肉力量（動態肌力及靜態肌力）的影響情況；第二、了解在本實驗中所測得之平衡能力及兩項肌力間之相關情況。本實驗的研究對象爲99位健康正常的兒童，男孩有58位，女孩41位，年齡由9.6歲至12.7歲。此99位受測對象爲高雄市一所國民小學中之第4，5，6年級的班級中，經隨意選出的學童。研究步驟爲，在平衡能力測量方面，使用Bruininks Oseretsky Test of Motor Proficiency (BOTMP)中之第二次測驗，此次項測驗特別爲測量平衡能力所設計，其中共有8項施測細目。此外，使用BOTMP中之第四次測驗以測量動態肌肉力量。在靜態肌力測量方面，本實驗使用Force Evaluation and Testing System (FET)，以半蹲雙手提拉姿勢下取得量化的靜態肌力數值。並記錄每位兒童的身高及體重。用逐步迴歸統計法分析各項獨立自變數分別對平衡及兩項肌肉力量的影響情況。結果顯示體重及動態肌力爲估計平衡分數之有效預測因子；靜態肌力之有效預測因子爲性別及體重，而在預測動態肌力分數中，得知性別、體重、身高及平衡分數此四因子爲有效預測因子。斯皮爾曼(Spearman)相關係數分析結果顯示平衡分數與動態肌力分數間具有統計學上之明顯正相關，動態肌力分數與靜態肌力間也有明顯之正相關，而平衡分數與靜態肌力間爲顯著的負相關。其中詳細的分析載於文章的討論部份。

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