HUMAN CENTER OF GRAVITY DYNAMICS
A New Parameter Of Motor Development Functions

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Abstract

A study of a new parameter of human growth and development was conducted. The percentage of the height of body gravity center to the stature in supine position was measured in males and females during the period of pre-puberty (l995), young and adult puberties (1995 and 1997) and male adults (1995). The parameters measured were weight, stature and the height of the gravity center. Data were calculated in obtaining arithmetic means, standard deviations of all parameters and the percentage of gravity point height to stature. The percentages of male and female means, as well as standard deviations, were compared statistically. It was shown that in the pre-puberty group the location of the gravity center to stature was the same in percentage in males compared to females, whereas in the adult group (1987, 1995) a higher percentage was found in males. Among males (1995) differences were found in the percentages, which might have been caused by differences of body typology; the mesomorphic type showed the highest percentage, the endomorphic type showed the lowest, whereas the ectomorphic type it was in between.

Keywords: physical growth, development, motor function, body typology

Introduction

Several methods are used to evaluate physical growth and development i.e. by weighing, by measuring the stature or other body dimensions[1]. Physical development is evaluated by the degree of skilled and qualified movements, which symbolize the degree of neuromuscular functions maturity[2] Nelson[1] and Haywood[2] stated that physical growth is a qualitative increase in size of the body mass. The physical growth for the human species in males is the period between conception and approximately until 19-22 years, whereas in females the period is until 16-17 years[2,3]. Several authors stated that physical development implies a continuous process of change leading to a state of organized and specialized functional capacity. The physical development may occur in the form of qualitative or quantitative change or in both forms simultaneously[1,2,3]. *Physical motor function* reflects itself through the stages of the sequential, continuous, and age related process, by which an individual progresses from simple unorganized and unskilled movements to the achievement of highly organized complex motor skills and finally to the adjustment of skills that accompanies aging. This process is not limited to the period of physical growth; rather the development continues through the entire life span[2,3]. Physical motor functions are actually manifestation of the degree of neuromuscular maturation which develop craniocaudally as human neonate grows and develops.

Therefore the main point in the development of motor function depends largely on the quality and quantity of the development of neuromuscular apparatus. This fact is reflected in the body composition of the most advanced phase of motor function, that is in the adult, whose muscles comprise 43 % of the total body weight, where bone and marrow are only 14%, fat is 14%, visceral organs are 12 %,connective tissue and skin are 9%, while blood is only 8%[3]. Since muscle is trainable, either isotonically (in isotonic weight training) or isometrically (like in repetitive endurance activities such as running and cycling), therefore muscles can be hypertrophic; in this way, muscles or neuromuscular entity may seem to be the key factor in motor function[4].

Body build or body typology is inherited[1,5]. There are 3 types of body build, those are endomorphic, esomorphic and ectomorphic types. Those 3 types differ in many aspects of physical growth and development, and also in their body compositions. In short, endomorphic is fat dominant, mesomorphic is muscle dominant, while ectomorphic is linear bone dominant[6]. With these issues in mind one will judge that the mesomorphic type person will have the best motor performance. And this was proven by Tanner[7].

Every terrestrial body of mass will be influenced by earth gravitational force (Law of Universal Gravitation)[8], and the human body is no exception. This is called the body gravity which attracts every

particle of the mass. The resultant force of the particles that endure the gravity forces will have one working point within the body, which is called the center of gravity point. The position of this point is certain and fixed for the solid uniform mass, but for the uniformed ones like human body, the location is subject to change, depending on the unit of moment that creates the equilibrium of the whole body[8]. The unit of body moment, depends upon distribution of body mass, *mainly muscles* and *bones*, position of the body, limbs, body fat, and viscera.

Growth and development of the human physical body will change mass composition, mass distribution, and body proportion, *so does the center of body gravity*.

Based on all facts, the pattern of the center of body gravity movement during growth and development or *dinamic of the gravity point has multifactorial backgrounds, related to growth, development, activities, training, and body typology*.

A study which showed the dynamics of body gravity center, which is the movement of centers of neonatal body gravity was conducted with pedoscope instrument by Maekawa et al.[9]. The results indicated that the movement of the gravity center was concomitant with the activity of the extremities which were sluggish after delivery but both were concomitantly increased to reach the peaks within 1 to 3 days and then temporary decreased before both increased again; another study which was also done with pedoscope to show the dynamics of infant body gravity, in relation to motor development was conducted by T.Ando[10]. Results showed that the center of gravity in supine position was located at 10th thoracic vertebra at 2-4 months, then increased with the age until it was stabilized at 7th thoracic vertebra at 10 months of age. In prone position the center of gravity varied with a wide range wide range. It was located at 12th thoracic vertebra at 2-3 months, then ascended as far as 9th thoracic vertebra at 4 months to first half of 5 months, and descended thereafter to be stabilized at 2nd lumbar vertebra (level of navel) at around the age of 10 months.

The tendency towards certain type of body typology is genetically driven. It is manifested as a certain quality and quantity of physical growth and development, so that the outcome will be different in connection with mass composition, mass distribution and body proportion.

Considering all these facts, theories and assumptions, we realize that the gravity point dynamics should be worth for the assessment of physical growth, development, and motor function either for children, athletes. Therefore its role will be shown to be a benefit.

Since the location of body center of gravity is dependent on composition and distribution of body mass, also on body proportion, which are factors always changing during human life, the location of this body center of gravity will also change. Therefore this study was conducted in order to know the way the point of body gravity changed its location. On account of limited sample in this study it was assumed as follows:

1. There are differences in the height of body gravity during the stages of body growth and developments.
2. There are differences in the height of body gravity as manifestation of physical sexual dimorphism.
3. 3.There are differences in the height of body gravity as manifestation of body typology.

Methods

This survey was a cross-sectional study which meant that every subject was observed or measured on his/her characteristics once.

Human material. Twenty seven boys aged 9-12 years and 20 girls aged 9-12 years too but before having their menarche. They were pupils of the 6th grade elementary school and of first grade Junior High School. Data were obtained in 1995 in Jakarta. The second batch consisted of 22 males and 17 females, 3rd semester medical students, aged between 18-22 years. The data were obtained in 1995. Another batch of 80 males and 20 females 3rd semester medical students was studied in addition with 28 male adults, aged between 40 to 50 years.

All the subjects were musculoskeletally normal statically and dynamically. All of them joined the study voluntarily after being informed the objectives of study and the procedure of the examination. The examinations were done in the morning between 9 to 11 o'clock at the public elementary school and junior high school in Manggarai and at the Department of Anatomy, Faculty of Medicine, University of Indonesia in Jakarta.

All subjects were required to consume some food, wearing light, descent minimal cloth for females and only wearing underwear/knickerbockers for male, whereas all students/pupils should be barefooted during measurement.

The objectives and procedure of the study were informed, the agreement or objection was checked, followed by identification of name and age followed by determining health and menarche status. The following steps were measurements of weight and stature. The measurement of gravity point height was in supine

position, on gravity board with arms close to the body, hips were straight, knees and ankle were in neutral position of articulation. The instruments consisted of:

1. Harpenden Stadiometer for Outdoor Stature Measurement

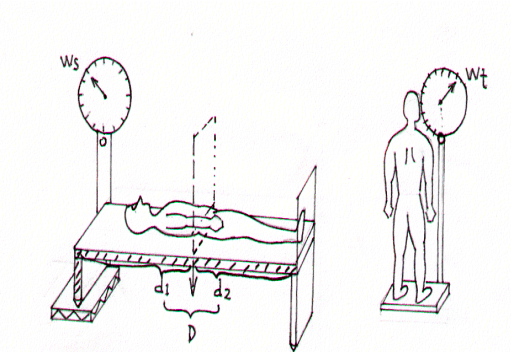

Figure 1. Gravity Board

2. Harpenden Stadiometer Wall Type for Indoor Stature Measurement.
3. Two weighing scales (SMIC)
4. Gravity Board (made by the author)(Figure 1).

Instruments and method of locating the center of gravity was derived from method developed by Lovetts and Reynold and revised by Cooper and Glasgow[8]. The method is based on the fact that when a body is in equilibrium, the sums of the gravitational moments acting on the body is equal to zero. The instrument is called the gravity board or reaction board (Figure1) which was constructed from a stiff board, two meter long, with the margin attached a centimeter scale tape. The zero mark was at one end and the 200 cm.mark was at the other extreme of the board margin. The board was supported with a blade on its each end. Then one of the reaction board blade was mounted to scale platform and the other blade was leveled in such a way so that the reaction board was in horizontal level. Then the scale was set to zero. The subject was then weighed with another scale and the body weight was registered as Wt. Then the subject was required to lay down in the reaction board with pternion (lowest heel point) at Zero Point of the board and the vertex (highest point of the head) in the direction of the scale. The scale needle showed the Ws value. Taking moments about the line of action of the body force (which line of action must pass through the board) the *clockwise moment*, CWM, was the product of the force recorded on the scale, Ws, and the perpendicular distance from the line of action to the blade edge resting on the scale. If the distance between the blade edge was D, then the *counterclockwise moment*, CCWM, about the body was the product of the weight supported by the distal blade edge (total weight minus weight registered on the scale i.e., Wt-Ws) and the perpendicular distance d2 from the distal blade edge and the plane containing the line of gravity (d2=D-d1).

By convention CW forces are considered positive and CCW forces are considered negative. Thus for Equilibrium:

Sigma M= CWM-CCWM = 0
CWM = Ws.d1=Ws.(D-d2)
CCWM = (Wt - Ws).d2
Ws.(D - d2) = (Wt-Ws).d2
Ws.D – Ws.d2 = Wt d2-Ws.d2
Ws.D = Wt.d2
Ws/Wt.D = d2 distance

$$d2 = \frac{Ws}{Wt} X\ D \qquad \text{(Formula 1)}$$

d2 or the height of the body gravity is obtained from formula 1, while D, Ws and Wt are measurable factors.

The Gravity Height is d2 if the pternion (heel point) were in zero position, the most distal point from the beam. This method is one plane method of locating center of gravity within a plane. There is also two planes method of locating center of gravity within a line. The point of gravity can be detected by combining the two methods with supine and with erect positioning.

Results and Discussion

The data are presented in Table 1, 2, 3 and 4, containing the number of samples, the value of means and standard deviations of 4 groups of samples. The height of gravity point was not presented as absolute figure but was calculated as percentage of stature with special consideration as argued in the discussion. The statistical calculation in comparing between two small samples, with their mean and standard deviation values, utilized the t test with probability <0.05.

Table 1 with data obtained in 1995 about pre-puberty groups of 27 boys and 20 girls of around 11 years old, showed boys were taller and also heavier than girls but boys center of gravity was lower than girls.

Table 1. Pre-puberty age 1995

	Male			*Female*		
	n	*X*	*sd*	*n*	*x*	*sd*
Age	27	11.3	2.2	20	11.05	2.2
Weight	27	31.1	1.05	20	29.6	2.2
Height	27	148	14.2	20	135.9	11
% of gravity height to body height	27	61%	13.5	20	61.30%	2.3

Table 2. Young adult age 1995

	Male			*Female*		
	n	*x*	*sd*	*n*	*x*	*sd*
Age	22	19.6	4.2	17	19.3	4.1
Weight	22	60.8	9.7	17	56.8	9
Height	22	169.2	4.9	17	157.5	5.8
% of gravity height to body height	22	56%	1.3	17	55.30%	1.8

Table 3. Young adult age 1987

	Male			*Female*		
	n	*x*	*sd*	*n*	*x*	*sd*
Age	80	21	1	20	21.5	0.7
Weight	80	54.9	8.5	20	46.7	6.7
Height	80	166.2	5.3	20	153.9	6
% of gravity height to body height	80	59.50%	6.9	20	52.70%	7.5

Table 4. Male adults 1995

Typology Tendency	*Percentage of Gravity Height to Stature*		
Typologies	n	x	sd
Endomorphic	6	52.30%	1.9
Mesomorphic	10	58.30%	2.3
Ectomorphic	10	55.60%	1.9

Table 2 with data obtained in 1995 about young adult groups of 22 males and 17 females of around 19 years old, showed that males were taller, heavier and higher center of gravity location.

Table 3 is with data obtained in 1987, about young adult age groups, 21 year old males and 21,5 year old females. The male group was taller, heavier and with higher center of body gravity.

Table 4 is with data obtained in 1995 on about mid forties males, 6 males of the endomorphic type, 10 males of the mesomorphic type and another 10 males of the ectomorphic type. The endomorphic type showed the lowest center of gravity point location, the mesomorphic type showed the highest location of center of body gravity, whereas the mesomorphic type the location was in between.

Boys were taller from 1 year to 12 years old, however after two years, girls would overrun boys, and then at the age of 16 years old, boys would be taller than girls[7]. The boys' body weight was heavier from birth to 5 years old then afterward the weight of boys and girls increased with the same speed until 12 years old. Between 12 to 16 years old girls would grow heavier than boys and towards later adulthood, boys exceeded girls, as a manifestation of sexual dimorphism.

In Tables 1, 2 and 3 the height and weight of all female groups were less than those of boys of the same age. In tables 2 and 3 are shown that at the time they already achieved adulthood, the results were due to the presence of sexual dimorphism. However in the groups of 9 to 12 years old the attainment of both height and weight of the girls were less (Table 1). This might be the phenomenon of the pre-puberty phase in an exaggerated form. The height of body gravity from the sole of foot could be presented in an absolute measurement[11] and/or be related to the body anthropometrical points such as omphalion (umbilical notch), symphision (upper middle point of symphysis osseum pubis) or iliospinale anterius (spina iliaca anterior superior)[12], or using pedoscope instruments for infants[9,10] or even by using multiple pressure transducers for adults so far as the facilities were accessible.

In observing almost the whole sample the author was suspicious to the sample and also the population were full of subjects with body dysplasia or *disproportionate type*. Since the real scientific method of diagnosing the dysplastic body should be by the Sheldon method of typology[5] in which it would be very time consuming, so this suspicion could not be proved. Consequently, the body point of gravity should not be related with the body anthropometric points, which might spoil the end result. Therefore it was determined to use the percentage of the gravity point height to the body height. Until the possibility of determining the body dysplasia is made easier by a new method we will still obtain the mixed result between the proportional body segments and the segments with dysplasia.

Table 1 is dealing with 27 boys, pre puberty period, 11 years old with a body weight of 37 kg, a body height of 148 cm., physically normal, the body gravity height was 61% against their statures and with 20 girls, before menarche, 11 years old, with a body weight of 29 kg, height 135 cm, the body gravity height was 61 % against their statures. Here it was detected that the boys were taller, heavier than the girls regardless of their similarity in their body gravity percentage. Also we might say that the similarity is due to minimal or absence of the development of secondary sex organ due to group was of the pre-menarche period. From this period on, girls will grow faster than boys and will cease growing sooner than boys at the age of 16 years old. Boys will still grow afterwards until 21-22 years.

The above result showed that the same gravity height for boys and girls of 11 years old, did not depend on their body height and weight as such, but rather depended on their development status as pre-pubertal

phase of development, when *their body proportions and mass distribution are similar*. Again, we see here that sexual dimorphism was not yet manifested. Basically before the puberty phase, boys and girls grow and develop parallel[7]. So, their gravity point percentages were the same, because they had the same physical growth phase.

Table 2 covers 22 males, 19 years old, 60 kg body weight and 169 cm body height which had the body gravity height points at the 56 % of their statures. The 17 females, 19 years old, 56 kg body weight, 157 cm body height had the gravity points at the height of 55 % of their statures. The comparison between the two means, using t test with the sample less than 30, with $p<0.05$, resulting in significant difference. Physical growth in young adult male of 19 years old has not yet finished, they are still growing. They can grow taller, a bit heavier, and consequently their body gravity height might be higher and their percentage will be greater. While young adult female of 19 years old, their attainment of height is finished. They might be heavier in certain parts of their body, mostly lower parts. A high possibility of attaining lower gravity point should be considered. Therefore the gravity point of young adult males, 19 years old, was significantly higher than that of female of the same age. In both sexes these young adult males and females had a lower percentage of gravity point than those of males and females in the pre-pubertal groups.

Table 3 which is on older group of 80 young adult males, 21 years old, body weight 54 kg, body height 166 cm with the percentage of body gravity points 59.5 % of their statures. The 20 females, 21 years old, 46 kg in body weight, 153 cm in body height, had their gravity points at 52 % of their statures.

This proved of the theory in the above paragraph which stated that males will attain more height in their gravity points while female will attain more masses in their lower parts of the body and therefore lowering their gravity points.

The Table 4 contained data of adult of mid forties only, and there were no female samples of that age. The absence of female samples was caused by (1) rejection of female samples of midforties to join the study; (2) the difficulties in identifying the somatotypology in adult women[5]. Nevertheless the male samples satisfied this pilot study.

Body typology or somatotypology in this study was not assessed accordingly to Heath and Carter method[6] but using anthroposcopical selection, implementing the whole body criteria as developed by Sheldon[5]. Total male adult samples consisted of 28 individuals, with 8 of the endomorphic type, and the gravity point was 52.3 % of their statures. Ten of the mesomorphic type and the gravity point 58.3 % of their statures and 10 of the ectomorphic typology with the gravity point 55.6 % of their statures. These results implied that in adult male the gravity point (52.3-58.3) was lower as compared with the young adult of 21 years old (59%). The body typology turned out to be specific with respect to body gravity height; the mesomorphic type was the highest, the endomorphic type was the lowest, while the ectomorphic type was moderate, in between. This specificity of gravity height is an important indicator for obtaining success in several sports activities such as jumping and all kinds of lifting sports. Individuals with a high center of body gravity are suitable for sports like jumping. While for sports like weight lifting, and the traditional Japanese sumo, a lower point of gravity is needed for their stability.

As a preliminary result we may say that the human body gravity is changing dynamically in accordance with the body growth, development, and typology. Therefore it can be utilized as a practical guidance toward evaluating motor function and performance[11].

Conclusions

1. *Males.* A) Body gravity point was the highest in pre-pubertal age (61% of stature), followed by 21 year old (59% of stature) and then 19 years old (56% of stature), concerning the body center of gravity dynamics. B) Gravity points of different body typology at mid forties were as follows: for endomorphic, the lowest it was 52.2% of the stature. For mesomorphics, the highest, 58.3% of the stature For ectomorphics it was moderate 55.6% of the stature, concerning the difference in body typology.

2. *Female* body gravity point was the highest in pre-menarche (pre-puberty period), decreased in the 19 years old and was the lowest in 21 years old females. This is on body growth and development difference and on body center of gravity dynamics.

3. Body gravity points were determined not by age but rather by body growth and development (Discussion Table 2 and 3)

4. Sexual dimorphism in body gravity height manifested its appearance after puberty phase and was influenced either by growth or by development.

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