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GAIT ANALYSIS OF 7-10-YEAR-OLD CHILDREN OF KARACHI FROM NUTRITIONAL-STATUS PERSPECTIVE¶

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ABSTRACT

Gait analysis of a child is becoming more and more significant as observation of posture of a stripped child may generate false positives as the incumbent becomes conscious and assumes an abnormal posture. On the other hand, observing gait of an undressed child walking or running a number of steps may give clues to underlying musculoskeletal or neurological disorders. In this work, results of a study on a sample of 7-10-*year*-old students (68 boys; 65 girls), enrolled in a local school representing middle-class-educated families, are presented. The students were followed up from KG to class 3 (2011-2013). Heights and weights were obtained every year and a detailed gait examination was performed in classes 2 and 3, with the students completely disrobed except short underpants. A detailed Growth-and-Obesity Profile was generated for each child to determine the nutritional-status category (under-nutrition, over-nutrition, energy-channelization I-III), in which the child should be placed. The probability of spastic gait was found to be highest in children exhibiting energy-channelization II (stunting combined with obesity), *i. e.*, 32.00%, seconded by those manifesting energy-channelization I (tallness combined with wasting), *i. e.*, 21.43%. Over-nourished (tallness combined with obesity) children had 10.00% probability of having spastic gait, whereas under-nourished (stunting combined with wasting) children had 8.82% probability. Acutely malnourished children (both height and mass percentiles falling below 3) had 14.29% probability. A possible explanation of these results may be on the basis of asymmetric distribution of mass about the sagittal plane, which may create a torque responsible for spastic gait in such children.

Keywords: Energy channelization, spastic gait, force generation in transverse plane, asymmetric mass distribution, shifting of body center-of-mass

INTRODUCTION

Gait analysis of child is gaining more and more importance these days as posture observation of a child may generate a large number of false positives since the youngster may become conscious and assume an abnormal posture. However, videotaping an unclad child walking or running a number of steps one gets a pattern, which could be analyzed to find out if the child is suffering from any musculoskeletal or neurological disorder.

In the military and the paramilitary occupations as well as during a job interview gait is the first thing noticed. It is a pity that majority of our children are not trained to walk properly. One could observe children walking to school any morning to see just how do they place their feet on the ground while walking. Of course, one of the factors contributing to this may be the heavy weight of the bags carried by these children on one side.

In this paper, we are presenting research on a sample of school-going children to determine probability of spastic gait among those, who exhibit the phenomenon of energy-channelization.

PHYSICS OF THE HUMAN GAIT

Human gait studied from a physics perspective provides an understanding of mechanical properties of the human skeleton and gives clues to the gross and the fine motor functions of a child. In order to understand physics of human gait, there is a need to review concepts of mechanical equilibrium and inverted pendulum.

Mechanical Equilibrium

Mechanical equilibrium, static or dynamic, is achieved, when the sum of forces as well as the sum of torques acting on a body vanishes. By studying potential-energy curve (potential energy vs. position) in a given region, one may classify mechanical equilibrium into three types**:**

*Stable Equilibrium***:** Stable equilibrium occurs, where potential-energy curve has a local minimum. In stable equilibrium, a particle experiences a force towards the equilibrium position upon slight displacement.

*Unstable Equilibrium***:** Unstable equilibrium occurs, where potential-energy curve has a local maximum. In unstable equilibrium, a particle experiences a force away from the equilibrium position upon slight displacement.

¶Main contribution of PhD dissertation of the second author, registered from Department of Physics, University of Karachi

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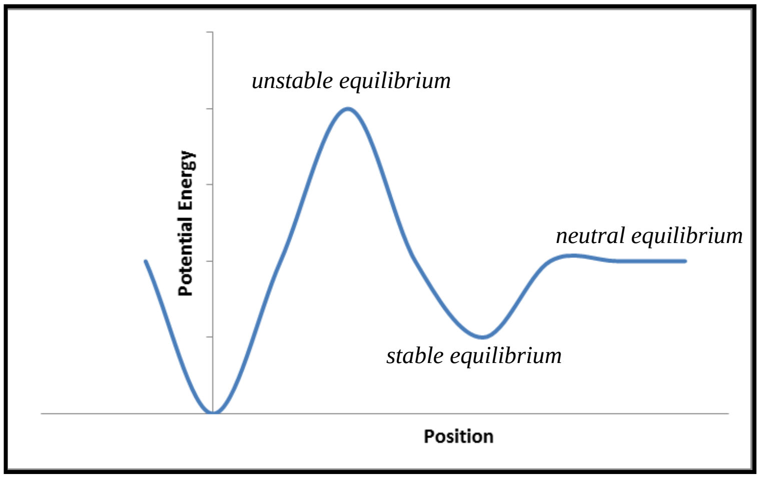


Fig. 1. Graph of potential energy vs. position to illustrate conditions of equilibrium

*Neutral Equilibrium***:** Neutral equilibrium occurs, where potential energy is constant in a given region. In neutral equilibrium, a particle does not return to its original location upon slight displacement. However, the new location is, also, an equilibrium position.

Figure 1 depicts graph of potential energy vs. position, which shows conditions for stable equilibrium, unstable equilibrium and neutral equilibrium.

Inverted-Pendulum Model

Consider a simple pendulum, which is hung from a fixed support. Let ℓ be the length of pendulum, which consists of a bob of mass m — the length ℓ includes length of string, length of hook used to attach bob to the string and radius of the bob. When this pendulum bob is raised to an angle, θ (measured from the vertical), the potential energy, $U(\theta)$, may be expressed as (Figure 2)**:**

(1) $$U(\theta) = mgh = mg\ell(1 - \cos\theta)$$

where g is the acceleration due to gravity. To obtain extrema, we differentiate the above and equate to zero

(2) $$\left.\frac{dU(\theta)}{d\theta}\right|_{\theta=\theta_0} = mg\ell\sin\theta\big|_{\theta=\theta_0} = mg\ell\sin\theta_0 = 0$$

Solving for θ_0, we get two values, *i. e.*, 0^0 and 180^0. In order to decide, which one corresponds to minimum or maximum energy, we check sign of the second derivative of potential energy at $\theta_0 = 0^0, 180^0$ corresponding to normal as well as inverted pendulum**:**

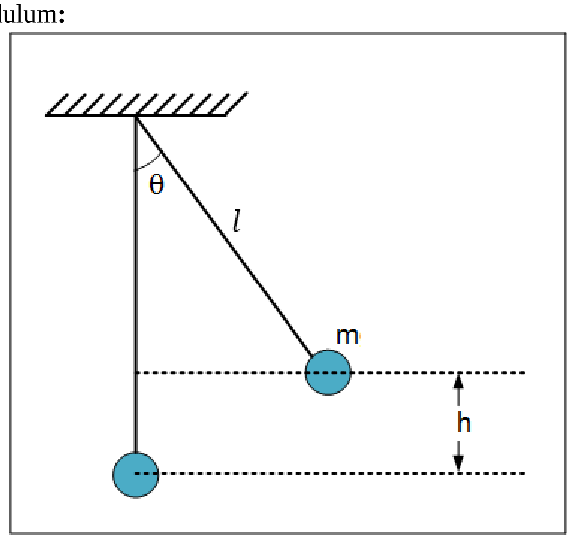


Fig. 2. Oscillation of pendulum**:** Calculation of potential energy

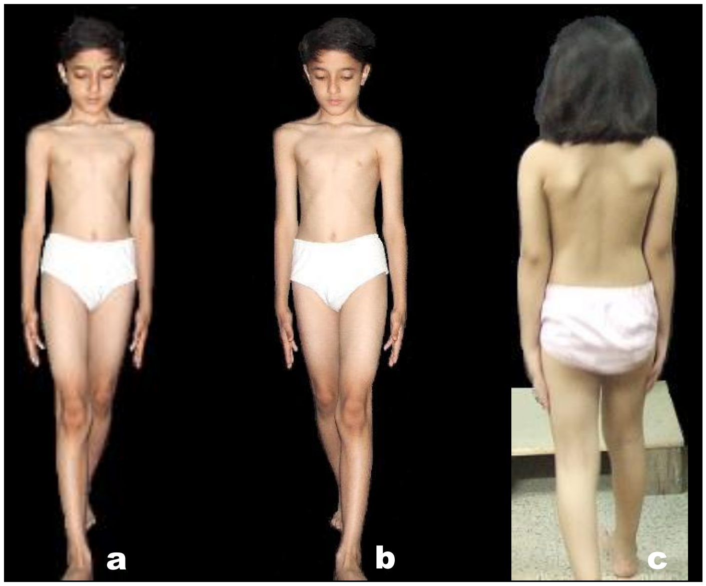


Fig. 3*a*-*c*. Observation of gait approaching and moving away

(3) $$\left.\frac{d^2U(\theta)}{d\theta^2}\right|_{\theta=\theta_0} = \frac{d}{d\theta}\left(\frac{dU(\theta)}{d\theta}\right)\Bigg|_{\theta=\theta_0} = \frac{d}{d\theta}(mg\ell\sin\theta)\Bigg|_{\theta=\theta_0} = mg\ell\cos\theta\Big|_{\theta=\theta_0} = mg\ell\cos\theta_0$$

At $\theta_0 = 0^0$, value of the second derivative is $mg\ell$. This value is positive. Hence, the potential energy is minimum at this point, corresponding to 'stable equilibrium'. At $\theta_0 = 180^0$, value of the second derivative is $-mg\ell$. This value is negative. Hence, the potential energy is maximum at this point, corresponding to 'unstable equilibrium'.

Application of Concepts

The bipedal locomotion of a child could be studied from kinesiological and biomechanical perspectives. During walking child's legs are activated out of phase with one another in each step. A state of unstable equilibrium occurs even while standing on two legs. This situation is modeled as an inverted pendulum. The feet provide a narrow base of support for the body's center of gravity. Each step of gait may be considered as an unstable fall followed by a return to stable posture.

Energy Expenditure

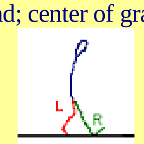
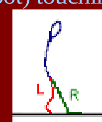
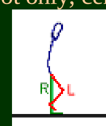
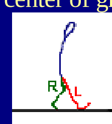
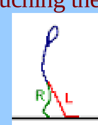
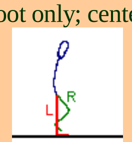
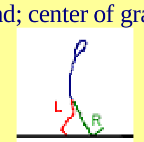
Prevention and treatment of under-nutrition and obesity (Kamal, 2015*a*-*c*) in children suffering from neurological disorders, in particular, cerebral palsy requires a thorough understanding of their needs for nutrition and, above all, energy requirements through measurement of total-energy expenditure (Bell and Davies, 2010). This would become efficient (accomplished in the least amount of time) and effective (no relapse of the condition treated) if energy-requirement analysis is combined with nutritional-status classification (acute-malnutrition with determination of severity, if present, under-nutrition, over-nutrition, energy-channelization I-III) by generating Growth-and-Obesity Roadmap of such a patient (Kamal, 2015*a*).

COMPUTER SCIENCE OF THE HUMAN GAIT

Gait analysis could be visualized as a problem of pattern recognition. The pattern could be recognized by analyzing video clips of a child's gait (Figures 3*a*-*c*).

A dynamic model of the human spinal column was presented by the first author (Kamal, 1996*c*). This mathematical-computer model was generalized from static model of the human spinal column (Kamal, 1996*a*). This model explained movement of the human spinal column during a gait cycle. The human spinal column in 3-D was generated from AP-X rays (AP stands for anteroposterior) or moiré topographs of back in the attention position (person standing with head straight, feet together, knees and elbows extended, palms on thighs) as well as during the first, the second, the third and the fourth gait-cycle steps. Shape of spinal outline in the attention position (Kamal, 1982) was linked to position during the first step of gait cycle through edge-based algorithm. Similarly, position in the second step was linked to the first step through edge-based algorithm and so on.

Table 1. Steps of normal gait of a child (right leg: green; left leg: red)
(terminologies explained in Additional File)

	Right Leg		*Left Leg*
Step 1: Right leg forward, left toe and right heel touching the ground; center of gravity lying between the two feet			
Hip	Extension		Extension
Knee	Extension		Extension
Ankle	Dorsiflexion		Planter Flexion
Mirror Image of Step 4; identical to Step 7			
Step 2: Right leg forward, right toe and right heel (that is, the right foot) touching the ground as well as left toe on ground			
Hip	Extension		Extension
Knee	Flexion		Flexion
Ankle	Neutral		Neutral
Mirror Image of Step 5			
Step 3: Left foot in air (moving forward), body supported by right foot only; center of gravity lying on top of right foot			
Hip	Flexion		Flexion
Knee	Flexion		Flexion
Ankle	Neutral		Neutral
Mirror Image of Step 6			
Step 4: Left leg forward, right toe and left heel touching the ground; center of gravity lying between the two feet			
Hip	Extension		Extension
Knee	Extension		Extension
Ankle	Planter Flexion		Dorsiflexion
Mirror Image of Step 1			
Step 5: Left leg forward, left toe and left heel (that is, the left foot) touching the ground as well as right toe on ground			
Hip	Extension		Extension
Knee	Flexion		Flexion
Ankle	Neutral		Neutral
Mirror Image of Step 2			
Step 6: Right foot in air (moving forward), body supported by left foot only; center of gravity lying on top of left foot			
Hip	Flexion		Flexion
Knee	Flexion		Flexion
Ankle	Neutral		Neutral
Mirror Image of Step 3			
Step 7: Right leg forward, left toe and right heel touching the ground; center of gravity lying between the two feet			
Hip	Extension		Extension
Knee	Extension		Extension
Ankle	Dorsiflexion		Planter Flexion
Identical to Step 1			

MATHEMATICS OF THE HUMAN GAIT

Steps of the human gait (1-7) are given Table 1. This table is an extension of the table, describing steps 1-4 given in (Kamal *et al.*, 1996). One may note that step 4 is the mirror image of step 1, whereas step 7 is identical to step 1. Hence, one notices that the human gait represents a periodic motion, which could be analyzed utilizing the mathematical techniques dealing with periodic functions, *e. g.*, Fourier series.

Additional File (http://www.ngds-ku.org/Papers/J41/Additional_File.pdf) lists anatomical terms, cardinal planes and anatomical axes as well as definitions of flexion, extension, dorsiflexion, planer flexion, gluteus maximus, tibialis-anterior muscle and triceps-surae muscle — last 3 mentioned in the upcoming section ‘Physiology of the Human Gait’.

PHYSIOLOGY OF THE HUMAN GAIT

The gait pattern could be analyzed to determine if the child is suffering from disorders of the neurological or the musculoskeletal origin. Van der Krogt *et al.* (2012) described a paradigm to determine the robustness of human gait to muscle weakness. Samania *et al.* (2011) reported improvement in gait after repetitive locomotor training in pediatric patients suffering from cerebral palsy. An abnormal gait may become the first indicator of CNS (Central Nervous System), trunk or lower-limb problems (Kamal *et al.*, 2013).

Orthopedic Perspective

The trunk deformities, which may affect gait, include scoliosis, kyphosis, lordosis, kypholordosis or flat back. Knees knocking, flat feet or accentuated curvatures of feet could, also, influence gait of a child.

*Normal Gait***:** Normal gait of a child exists in the sagittal plane. The gait of a soldier is an example of normal gait. Among the birds, rooster's gait resembles closely to normal gait of a human being.

*Spastic Gait***:** Spastic gait occurs in the sagittal as well as the transverse plane. During walking, hips swing leftward or rightward. A duck's gait could be approximated to spastic gait of a human being. Spastic gait may occur due to hip weakness. Hip weakness is suspected though positive forward-bending and visual tests looking for asymmetry of back (both conducted with the undressed child sitting on a stool), indicated through positive Tredelenburg sign — child instructed to lift each foot for a count of 3 and pelvis level is observed. When weight is borne on weak hip abductors, the pelvis tilts upward on the side of the affected hip (Kamal *et al.*, 2015*a*). This may be understood from the analogy that the pan of balance carrying lighter weight is at a higher level as compared to the other pan.

*Limp***:** A limp occurs in the sagittal as well as the frontal plane. It may be due to leg-length inequality or inability of exerting full force on one of the legs due to muscle or bone weakness caused by some disease, *e. g.*, polio. A dog or a cat with one leg wounded exhibits limp. Leg-length inequality is suspected though positive forward-bending and visual tests (both conducted with the child standing, divested of everything except underwear), indicated through uneven spinal dimples (Kamal *et al.*, 2015*a*).

Neurological Perspective

*Theoretical Basis***:** According to Neuronal Group Selection Theory (NGST) put forward by Edelman (1987) and enhanced by Spoms and Edelman (1994), neuronal groups are organized as neural maps in separate brain areas. Activities of motor and sensory regions are assimilated by reciprocal group connections, which are long reaching. Every child has unique neural maps as a result of the individual's specific motor experiences, which are, constantly, breaking and reforming till they reach the peak at the age of 10 *years*. The brain development or brain damage recovery is facilitated during various activities; in particular, those performed in developmentally or functionally appropriate environmental background. The child moves to satisfy demands of the task given to the incumbent. Iosa *et al.* (2012) studied stability and harmony of gait in children with cerebral palsy.

*Tests to be Performed***:** Unclothed child may be instructed to walk tandem (heel-to-toe) to assess balance and look for poor position sense, vertigo (a sensation of rotation or movement of self or surroundings) and leg tremors. Further, one must check for asymmetry of arm swing, which may be indicative of mild hemiplegia. If any abnormality is suspected, the child may be required to walk on tiptoe, to check for triceps-surae-muscle weakness, and on the heels, to look for tibialis-anterior-muscle weakness. If gluteus maximus is suspected, the child may be asked to move forward on the knees. A vertical position of the upper torso indicates good gluteus maximus strength (Cottalorda *et al.*, 2012).

METHODS OF GAIT ANALYSIS

The gait of a child starts developing around the age of 7 to 8 *years*. A meticulous observation of gait must be an essential part of stripped physical examination of all children promoted to class 2. The gait should be studied both during walking and, then, running 20 to 30 steps. The child is asked to walk on solid ground and, then, on sandy path. For a child possessing normal gait, footprints on sand should be the mirror image from step 1 to step 4. This could be organized as a game without letting the child feel that gait is being evaluated.

Naked-Eye Observation vs. Computerized Analysis

Gait analysis can be a simple naked-eye observation of walking of a child or a sophisticated 3-D-computerized-motion analysis with measurements of energy. In fact, 3-D-motion analysis helps enhance and fine-tune the information obtained from simple visual analysis, provided accuracy and reliability of the procedure is determined (Steif *et al.*, 2013). On the other hand, the authors of this paper make a very strong point that naked-eye observation of walking and running of the disrobed child (not the projected image on a video monitor or other such gadgets) by a gait expert is no substitute to computer-assisted gait analysis. In principle, the former should be the very first step in the series of examinations conducted in a gait laboratory.

Need for Undressing: For the purpose of gait analysis, child should have head uncovered. Short hair may be left open. However, long hair should be tied on top of head in the form of (hair) bun to allow visualization of the entire spinal column from external auditory meatus to hip joint (Kamal and Khan, 2015). The child should be barefoot, completely undressed from the waist up, attired solely in white exercise (gym) briefs or panties (Figure 3), which are form fitting and made of absorbent material (Kamal and Khan, 2014).

Effect of School Bags on Gait: The heavy weight of the school bags carried on one side may contribute to an impaired gait (Kamal *et al.*, 1998). The gait is observed by requiring the child to travel 20 steps to touch wall and return. The child may be asked to repeat the same task, while wearing school bag. Difference in posture and gait is noted with and without school bag.

Gait — Walking and Running: Böhm and Döderlein (2012) studied gait asymmetries in children with cerebral palsy, with a focus on change of gait pattern from walking to running. They compared gait for 2 groups of patients — diplegic and hemiplegic. They report that in both patient groups asymmetry increases noticeably, when the mode is changed from walking to running.

Formal-Gait vs. Spontaneous-Gait Observation

During a formal gait observation, the child may become conscious that the incumbent's gait is observed. Hence, there could be some artificiality introduced in the movements of hands and feet. It is, therefore, highly recommended that spontaneous gait should, always, be scrutinized to discover CNS problems. An opportunity for such an observation is offered, when the child leaves the examination area (still devoid of clothing) to proceed back to the dressing area. During such passive observation the child does not become conscious that gait is being observed (Kamal *et al.*, 2014*a*).

GAIT ANALYSIS IN PERSPECTIVE

Wren *et al.* (2011) give an excellent literature review and references evaluating and summarizing present evidence-base related to clinical efficacy of gait analysis. Bovi *et al.* (2011) propose multiple-task-gait-analysis protocol, which includes self-selected, increased- and decreased-speed gait, toe-walking, heel-walking, step-ascending and step-descending to bring into light certain pathologies, which are not evident in plain gait, but manifest themselves in more demanding locomotor tasks. At, times, it becomes important to find out correlation of Gait Profile Score (GPS), a single index, which summarizes overall deviation of kinematical gait data relative to normative data, and Movement Analysis Profile (MAP), generated from 9 key-component-kinematic-gait variables. According to Beynon *et al.* (2010) strong, significant and positive correlations were found between GPS and MAP component scores and ratings of clinicians of kinematic gait deviation. Rueterbories *et al.* (2010) describe methods of gait-event detection and analysis in ambulatory systems.

Video Recording and Analysis

Video recording of gait has been of interest to researchers from a long time to permanently document the patterns. Hennessy *et al.* (1984) studied development of gait in children aged 1 to 5 from Gusii tribe of southwestern Kenya, Africa by film recording free-cadence walking. Boerel *et al.* (2011) reported that the video-analysis software improved inter-rater agreement, which was measured by weighted Cohen's kappas. Harvey and Gorter (2011) gave the instances and the situations in which video gait analysis could be used in place of three-dimensional analysis.

Three-Dimensional Analysis

Bugané *et al.* (2012) used a single accelerometer to estimate spatial-temporal gait parameters during level walking. The three-axial acceleration signals were filtered and timing of the main gait events identified. The method was validated on normal subjects using standard gait analysis. Van den Noort *et al.* (2013) performed gait analysis in children with cerebral palsy via inertial and magnetic sensors. Carse *et al.* (2013) assessed marker-tacking accuracy of a new low-cost optical 3-D-motion-analysis system. Grunt *et al.* (2010) reported reproducibility and validity of video-screen measurements of sagittal-plane-joint angles during a gait cycle in children with cerebral palsy. Greene *et al.* (2010) described an adaptive gyroscope-based algorithm for temporal gait analysis.

Moiré Fringe Topography

Lewis and Moreland (1981) conducted a preliminary study to assess the feasibility of gait analysis using moiré fringe topography in examining topographic changes of back shape during a gait cycle. According to their study, several normal subjects exhibited a trend toward continual asymmetry throughout the gait cycle. Yousufzai *et al.* (1995)

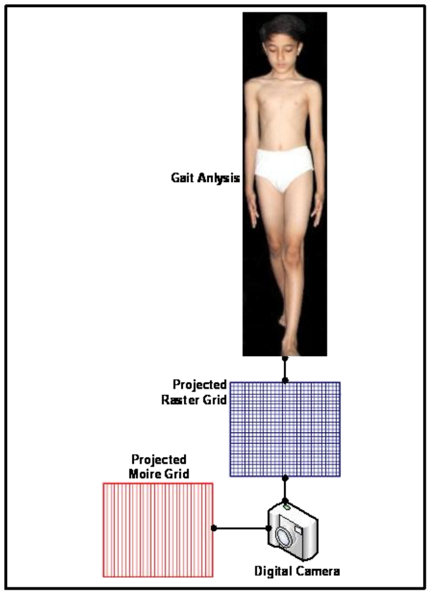


Fig. 4. Simultaneous moiré and raster recording

conducted computer-based analysis of human gait using moiré fringe topography.

Rasterstereography

Kamal *et al.* (1996) employed rastersterepgraphy to study gait pattern of a normal child and 2 polio patients. The idea was to determine curvatures at selected anatomical landmarks to determine how their relative position changed during steps 1-4 of a gait cycle. After initial experiments on a healthy child, it was decided to study both height and curvature maps by combining moiré technique with the raster technique.

Simultaneous Moiré and Raster

Kamal *et al.* (1996) investigated feasibility of simultaneous moiré and raster recording. A camera, two projectors, a raster grid and a moiré grid were used. Red color was used to construct the moiré grid and blue color to make the raster grid, which were projected simultaneously on the body as shown in Figure 4 and a color photograph was taken. A red filter (matching exactly with color of the moiré grid) was placed on this photograph, which caused the red-moiré grid to become invisible and the blue-raster grid to appear black. This black raster was analyzed using algorithm to generate mean and gaussian curvatures. Similarly, a blue filter (matching exactly with color of the raster grid) was placed on the picture, which caused suppression of the raster grid and black appearance of the distorted-moiré grid. This distorted grid was photographed and mounted on the wall. To generate moiré pattern from this distorted-line grid, an undistorted-back grid was projected at the same angle to produce moiré fringes by grating-hologram method. Distance was carefully selected so that magnification of the undistorted grid was identical to the distorted grid, so that proper pitch matching took place; the orientation chosen so that the angle did not exceed 45^0.

Edge-Based Moiré

Edge-based moiré was generated as a combination of moiré pattern and edge-based algorithm. Moiré contours gave height maps in a plane normal to the image. Moiré patterns altered, when the object moved infinitesimally towards or away from the camera. Consider moiré patterns of a child walking. With the motion, the moiré patterns changed. When the child moved away from the camera, the patterns around scapulae started converging and appeared to sink at the respective scapula. Movement away from the camera, therefore, represented a sink field in the moiré patterns of the convex surface, corresponding to negative divergence of optical-flow field. When the child walked towards the camera, new diverging patterns appeared. Movement towards the camera, therefore, represented a source field in the moiré patterns of a convex surface, corresponding to positive divergence of optical-flow field (Kamal, 1996*b*).

Edge-Based Raster

A combination of edge-based algorithm and raster pattern, edge-based raster dealt with changing curvature maps instead of height maps. Raster patterns altered, when the object was moving infinitesimally towards or away from the camera. Consider raster patterns of a child walking. Because of movement of body, the raster patterns

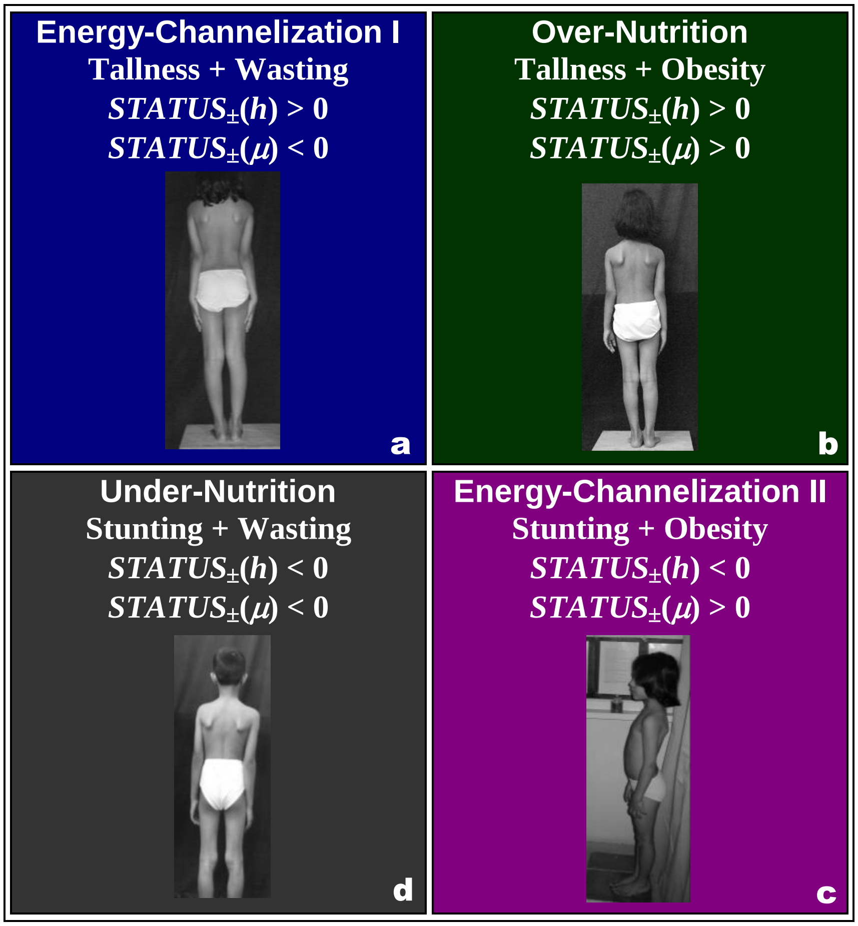


Fig. 5*a-d*. Nutritional-status classification I**:** Coördinate-plane representation — clockwise from upper left, energy-channelization I, over-nutrition, energy-channelization II and under-nutrition

changed. The new and the old patterns were linked through edge-based algorithm and curvature change was plotted as a vector field (Kamal, 2008).

ENERGY-CHANNELIZATION (EC) IN CHILDREN

Energy channelization was introduced recently (Kamal *et al.*, 2014*c*). For stunted and wasted children, under-nutrition (UN) might be the main concern. Tallness plus obesity, which amplifies tissue-synthesis rate and storage in body, may be termed as over-nutrition (ON). The remaining two possibilities, tallness associated with wasting and stunting associated with obesity, might show up due to energy-channelization problem in body, the first one termed as energy-channelization I (EC I) and the second one as energy-channelization II (EC II). These conditions are caused by a large amount of micronutrients, all flowing through one channel of absorption. Stunting with obesity may be caused by storage of most micronutrients; whereas tallness with wasting, could result from micronutrients, mostly, involved in tissue synthesis. Figures 5*a-d* show pictorially over-nutrition, under-nutrition and energy-channelization I (tallness + wasting) and II (stunting + obesity). These nutritional statuses were determined using a child's Growth-and-Obesity Profile (Kamal *et al.*, 2011) and become part of each child's Growth-and-Obesity Roadmap (Kamal *et al.*, 2015*b*).

Acute malnutrition (AM) is the limiting case of under-nutrition, when both height and mass percentiles fall below 3rd *percentile* (Kamal and Jamil, 2014). Such a condition demands immediate medical attention. It may be due to a chronic disease (cardiac, respiratory, renal or malabsorption). In a recent work, the first author suggested a mathematical definition of 'severity of acute malnutrition' (Kamal, 2015*a*). Puberty-induced energy-channelization, also, termed as energy-channelization III (EC III), was introduced, recently, as limiting case of over-nutrition (Kamal and Jamil, 2014). This is characterized by height-gain leveling off combined with gain in mass as well as below-waist fat. The limiting cases, acute malnutrition and puberty-induced energy-channelization (EC III) are

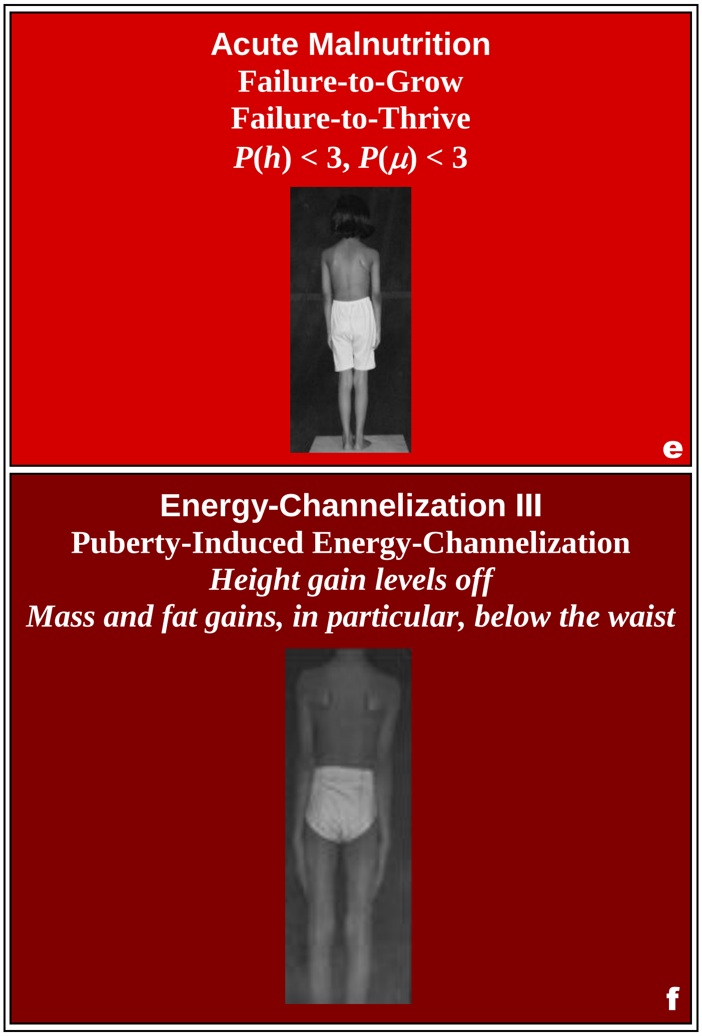


Fig. 5*e, f*. Nutritional-status classification II**:** Extreme cases — from top to bottom, acute malnutrition and energy-channelization III

shown in Figures 5*e, f*.

Force Generation

EC I (tallness + wasting) and EC II (stunting + obesity) may contribute to asymmetric distribution of mass about the sagittal plane causing generation of force and, hence, a torque about body's center of gravity during walking. Such a force may be the cause of abnormal gait in EC children.

Spastic Gait in EC Children

As mentioned above, an unbalanced force about the sagittal plane may produce a torque, which may cause an EC child to exhibit spastic gait. In this work we are presenting results of such a study.

SUBJECTS AND METHODS

This work reports gait analysis and nutritional-status determination of the students during 2011-2013. Students studying in KG were enrolled and followed up till they left class 2. Some students were measured, while they were studying in class 3. Since the data were collected almost at the end of academic year, students in KG were 5.5- to 7-*year* old at the start of study and they were 8.5- to 10-*year* old in class 3. Data of 68 boys and 65 girls are presented. Anthropometry was performed in each year and a detailed gait examination was conducted in classes 2 and 3.

Study Design

The study was organized under the umbrella of the NGDS Pilot Project (http://ngds.uok.edu.pk) a public-service, goodwill endeavor for the care and the development of youngsters of this nation to prepare them physically, emotionally and mentally for rewarding careers in the civil and the military services. This project is being carried out successfully since 1998.

Purpose of the Study: The study was designed and conducted with the following 2 objectives in mind:

- To determine relationship between spastic gait and energy-channelization in 7-10-*year*-old children
- To compute probability of spastic gait (gender-wise) in various nutritional categories.

Study Type: This was an observational and a longitudinal study.

Sampling: Convenience sampling was employed. Data reported in this paper were collected on the students studying in a civilian school serving a middle-class locality in Karachi, Pakistan.

Institutional Review Process and Informed Consent: Study protocols were designed after considering prevailing European as well as North American human-right and ethical standards. These protocols were approved by 'Institutional Review Board' of University of Karachi, which comprised of committees consisting of chancellor and vice chancellor. 'Informed Consent Forms' (http://www.ngds-ku.org/BLA/Form_BLA.pdf), based on Opt-in Policy (participating students must give evidence of parents' permission), requiring signatures of mother, father and the student concerned were sent to families and filled-in, signed slips collected back. Verbal consent was taken prior of checkup and privacy of students respected. Confidentiality of data was ascertained by assigning codes to each case number.

Inclusion/Exclusion Criteria: All the students, who were not suffering from serious ailments, were included in data analysis. One boy, who had multiple musculoskeletal deformities and could not stand straight or walk unaided, was excluded at the data-processing stage.

Organization of the Study

A dedicated room was provided by the school authorities, which was furnished according to examination needs. Both acoustic and visual privacy was provided, as the students were required to remove clothes for the examinations. Girls and boys were separated for the checkups. During girls' examinations, a female assistant was, always, present.

Preparation for the Study

The Project Director went into each class to introduce the procedures and brief about the project benefits to the students. The questions raised by the students as well as their teachers were answered to their satisfaction.

Conduct of the Study

On the day of checkup the NGDS Team checked the floor, in particular, checking for any sharp objects (paper clips, pins, staples, *etc.*), which might inflict injury to bare feet of children. The benches were checked for sharp edges or broken wood, the wall-mounted tape for measuring height was checked to make sure that both sides of the engineering tape were adequately covered by transparent tape as these sides were sharp and could cause cuts to bare skin of children. Comfort of the students was of prime concern. In mild weather fans were turned off, as students were required to take off clothes for measurements and could catch cold. Before the start of each daily session, equipments were checked for safety and calibrated. After discarding their school uniforms, the students were given a general checkup, including inspection of skin, hair, nails, palms, inside of mouth, teeth as well as a quick cardiac examination. Their heights and masses were recorded according to procedures given elsewhere (Kamal, 2006). Their gaits were observed from front and back to look for spastic gait, limp and toes inward/outward.

Data Collection and Analysis

Data were collected on weekdays (Monday to Friday) in the morning hours. They were analyzed by first computing Growth-and-Obesity Profile (Kamal *et al.*, 2011) of each student to classify nutritional status (Kamal, 2015*a*). The probability of spastic gait in each gender was computed using the following equation:

$$\textit{Spastic-Gait Probability} = 100\frac{N_{\text{spastic}}}{N_{\text{spastic}} + N_{\text{normal}}};\ N_{\text{spastic}}(N_{\text{normal}}) = \textit{Number of children with spastic (normal) gait}$$

RESULTS AND DISCUSSION

The results indicate higher probability of spastic gait in EC children — 21.43% in EC-I and 32% in EC-II. Girls seem to have a higher risk of exhibiting spastic gait, may be due to their weak skeleton. The probabilities in each

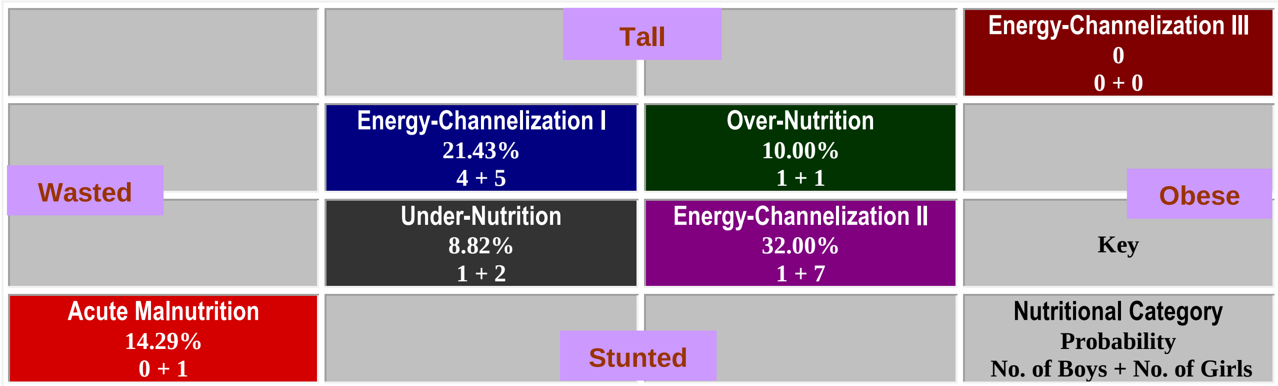


Fig. 6. Probability and gender-wise distribution of spastic gait in each nutritional category

nutritional category (gender-wise) is shown in Figure 6.

The higher probability of spastic gait in EC children may be explained by considering that energy-channelization creates imbalance between the amount of mass a child has as compared to the youngster's height. Asymmetric distribution of mass about the sagittal plane may create a force and the resulting torque could be attributed to spastic gait in such children.

FUTURE DIRECTIONS

Future techniques of study of gait could employ dotted-rastersteography (Wasim *et al.*, 2013) for dynamic-body-surface studies as well as backscatter-X-ray-dotted-rasterstereography (Kamal, 2013) for dynamic spinal-column-surface studies. Long-term objectives may include gait analysis from the perspective of crystal-structure-based-dynamic modeling of the human spinal column (Kamal *et al.*, 2012; 2014*b*).

The clinical problems, which could interest the researcher of tomorrow, are investigation of relationship of spastic gait with hip weakness, with a possible classification of acuteness of condition. Some preliminary work has been done (Kamal *et al.*, 2014*a*). Similarly, relationship of limp with leg-length inequality is worth studying, with a possible classification of seriousness of condition. Asymmetric force about the transverse plane, due to energy-channelization (EC), may produce a torque, which may cause limp in EC children. Therefore, limp study in such children may increase knowledge of mechanism of gait. Further, gait abnormalities may be looked in children suffering from acute malnutrition, possibly relating them to 'severity of acute malnutrition' (Kamal, 2015*a*).

CONCLUSION

This paper investigated probability of spastic gait in various nutritional categories, in particular for children, who manifested energy-channelization problem. The diagnostic value of gait as a fine indicator of motor-function disorder should not be underestimated. Gait analysis should be placed at the top of a multi-level screening of school-age children as well as job seekers. Gait may, also, become an indicator of self-esteem during catwalk, identifier of individuals, who are only observed from rear as well as predictor of hostile intent in sensitive environments.

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