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**Design & Development of Scientific Footwear for Toddlers**

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**Abstracts**

The toddler years of an individual (from 1 year to 3 years) are the formative years of foot health and development. Footwear impacts the formation of the gait during these early years as the feet are vulnerable and can be molded according to the footwear that they are housed in. There remains a lacuna in the research and development of toddlers' footwear due to the small market share and limited product usage. The Indian market fails to cater to the requirements of this segment as there exist no technical specifications for the toddlers' footwear. The present study assesses the toddler's footwear available in the Indian market. The paper aims at designing scientific footwear that can help attain a gait in shod condition as close to the natural gait of an individual. The authors have looked into the architectural requirements of toddlers' footwear and the materials that are suitable to be used for developing prototype. Comparison of commercially used materials for various shoe components reasons out selection of the material to be used for developing toddlers' shoe which is high on comfort and is able to give a good fit. Through the study the authors have been able to give recommendations for materials, patterns and the length and the width allowance to be included while designing footwear for toddlers.

**Keywords:** fit, sizing, gait analysis, design derivations, architectural derivations, prototype development.

**Introduction**

The toddler years of an individual (from 1 year to 3 years) are the formative years of foot health and development. As the toddler learns to toddle on the floor carefully placing each step and trying to balance oneself, the choice and fit of footwear becomes very important. There have been many studies done on the type of footwear and studies discussing whether shod or unshod condition is best for the development of foot. According to Dr. Rossi, a leading chiropodist, absence of scientific standards are the missing links in fields of foot health and footwear. Physicians, orthopedists, chiropodists, shoe fitters, shoe manufacturers, all have individualized approaches to foot health, with the result that no one knows what is a 'normal foot,' a 'good shoe,' or how to evaluate a foot.

Footwear is rigid object designed to cover a flexible movable object (Staheli, 1981). A shoe is nothing but an aesthetically designed gear for a flexible and complex small structure- the foot. Toddlers' feet have soft bones and more of cartilage which harden with age and the sensory experience with the surface they walk on. The role of footwear in the formative years of gait has been of interest to the researchers and the effect of footwear on gait formation among toddlers has always been controversial. There remains a lacuna

in the research and development of toddlers' footwear due to the small market share and limited product usage.

available in the Indian market. The paper aims at designing scientific footwear that can help attain a gait in shod condition as close to the natural gait of an individual. The study also deals with various architectural requirements of toddlers' footwear and the materials that are suitable to be used for making footwear for toddlers.

**Methodology**

In order to assess the toddlers' footwear in the Indian market, a survey of 500 toddlers was conducted to collect data of their feet measurements and establish a relation between the foot length, foot width and the ball girth. The sizes of the footwear being retailed in the market were compared to see if the requirements of the toddlers met.

To understand the architectural requirements of toddlers' footwear, the gait of the toddlers was recorded by using observation technique. Gait of 10 toddlers in shod and unshod conditions on different surfaces like marble floor, tiled floors, on grass and while climbing stairs was recorded. The toddlers were

made to wear similar style of closed as well as open shoe for the study.

Experiments of gait analysis were conducted on 6 toddlers using plate scanners (Fig 1) to establish scientific data for comparing the gait of an individual in static unshod condition. The results were used to devise design directions in order to design scientific footwear for toddlers.



Fig 1 : Toddler on the plate scanner

Choice of material was based on the primary and secondary research and analysis of the commercially used materials for various shoe components. Materials for upper, lining and sole for the prototype development were selected based on the test results of the materials. Prototype was developed and physical and scientific wear trials (through pressure plate scanners) were then conducted using the newly developed prototype. Conclusions were drawn suggesting the architectural requirements and the materials to be used for developing toddler's footwear.

### Data findings and analysis

#### Feet measurement

Feet of 500 toddlers were measured for length and width and the results were grouped according to the age of the toddlers. Variations in the foot size were mapped through the scatter diagram as shown in Figure 2.

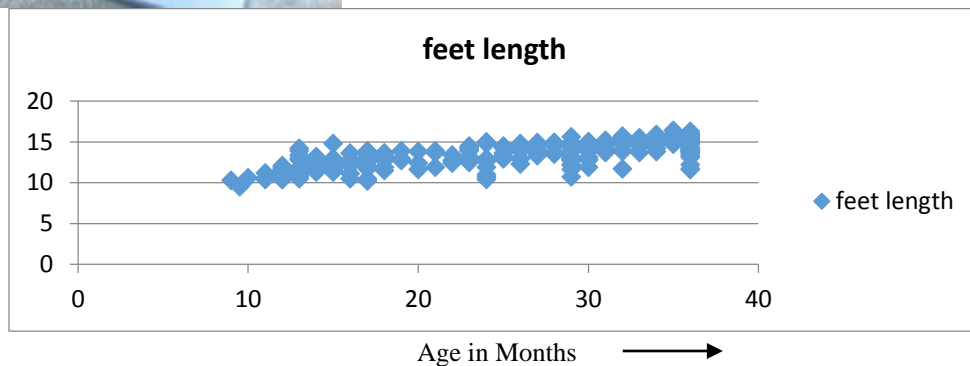


Fig 2 Scatter Diagram of Feet Size Among Toddlers

Variations in the width of the feet were also mapped and are shown in the scatter diagram in Figure 3.

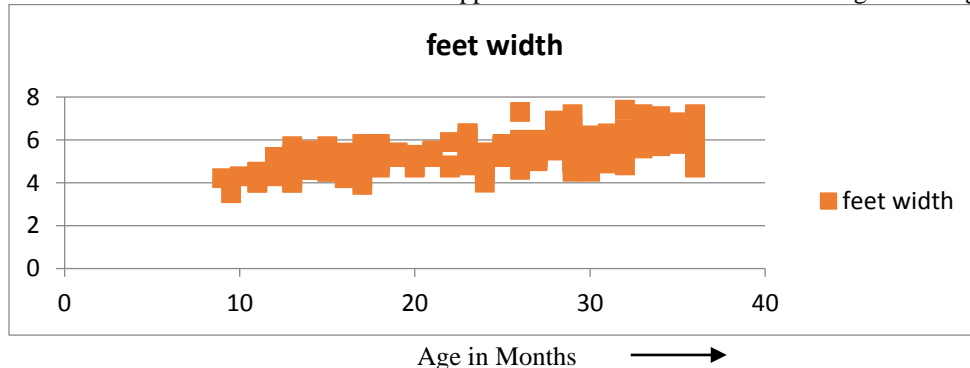


Fig 3 Scatter Diagram of Feet Width Among Toddlers

The foot widths of 15 individuals having foot length 15 cm were mapped on a tracing sheet to see the variations in the shape of the foot and difference in the widths at tarsal and the meta tarsal region. (Fig 4)



Fig: 4: Mapping of different foot shapes of foot length 15 cm.

**Comparison of Starting Sizes of Different Brands**

Starting sizes of some of the leading organized brands and some local brands of Indian toddlers’ footwear

were studied and compared. Table 1 shows the variation in starting sizes in closed and open toe shoes for toddlers.

Table: 1 Smallest Sizes of Footwear available in the market

S.No	Brand/ Label	Type of Shoe	Size	Inner Length (cm)
1	B	Closed Toe	19	12
2	C	Closed Toe	17	14.8
3	A	Closed Toe	2	13.5
4	D	Closed Toe	15	14.2
5	D	Open Toe	15	13.8
6	E	Closed Toe	19	11.7
7	F	Open Shoe	13.5	12.7

**Gait Analysis In Toddlers**

In order to understand the architectural requirements for designing scientific footwear for toddlers, gait analysis using pressure plate scanners and video recordings were done. The pressure distribution was

recorded for the toddlers in static position to compare the pressure borne by the left and the right foot and heels and toes of toddlers (Table 2). The analysis also gave insight in the difference in the foot axis angle for the two feet of each individual (Table 3).

Table 2: Pressure Distribution on left and right foot and on heels and toes in unshod static position

Toddler/	Age (mnths)/ weight( Kg)	Left Foot Pressure	Right Foot Pressure	Weight distribution on heels	Maximum Pressure exerted (N/cm <sup>2</sup> )
A	29/11	41.8	58.2	63%	10
B	23/14	55.8	44.2	60.9	16.9
C	18/12	48.5	51.5	53.2	10
D	14/9	40.2	59.8	37.9	4
E	31/16	43.6	56.4	62.4	5.3
F	32/20	78.4	21.6	73.3	19.7

**Table 3: Foot axis angle**

Age	29	23	18	14	31	32						
Sex	Male	Male	Male	Female	Male	Female						
Side	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Angle in Degrees	5.4	11.9	14.9	2	13.5	10.8	25.5	4	2.4	5.2	3.6	0

**Results and discussions**

The feet measurements show that the smallest size of the feet recorded was 10.2 cm, of 10 months old toddler. It has been observed that there are varying lengths of the feet in similar age groups ranging to a difference as large as 4 cm in case of 36 month old toddlers. The widths of the feet also show a varying difference in similar age group with a difference ranging to 3.1 cm in some categories. It was observed that different individuals had different feet shapes and widths. Hence the introduction of different last width is important as the variation in the width was observed to be as diverse as 3 cm.

The comparison of the starting shoe sizes show that there exists no consistency in the sizing and their inner lengths of the starting sizes. Brand A has the starting shoe size as 2 with inner length of 13.5 cm, Brand B starts the sizes with 19, with an inner length of 12 cm and Brand C has the starting size of 17 with inner length of 14.8 cm (Table 1). According to the retailers the starting shoe size would fit an 18-21 month old baby. Another interesting fact that comes across is that a size 19 of a brand has smaller inner length than size 17 of another brand (Table 1). It is evident that there exists no standard sizing pattern for the domestic market and every brand is working with its own sizing systems. It is also noted that the inner lengths have no bearing with the sizing mentioned on the footwear.

The smallest foot length recorded according to the data collected of 500 toddlers is seen to be 10.2 cm while the smallest inner length being retailed in the market is 12 cm by only one brand. While all other organized and unorganized brands have inner lengths above 13.5 cm for closed shoe. This shows that the market fails to cater to the requirement of the starting sizes according to the Indian population.

Gait analysis using plate scanners showed that in case of some toddlers the pressure was more on the right foot than the left foot. Among all the toddlers except one, the heels bore more pressure in static position than the toes. The maximum pressure exerted by the left and right foot was different among different toddlers. The foot axis was also different for the left

and the right foot. All toddlers shifted the body pressure between the heel and the toe and the body weight shifted from left to right even in static position. Analysis of the foot angle revealed statistically significant asymmetries between the left and the right side of the subjects. We thus find toddlers sway side to side rather than walking forward. This has been explained by earlier studies according to which these asymmetries have an important contribution in forming the characteristic gait of a subject.

The video recordings of the toddlers in barefoot and using branded commercial footwear were observed to understand the gait patterns among toddlers. Gait parameters (walking speed, stride length, foot lift) were observed and compared across conditions and 10 subjects. The toddlers sway from one side to the other as they are not able to grip the ground firmly and walk with firm confident steps. They walk with their arms spread and heels touching the ground the least. Their response to different textures of the floor was also seen to be different. On polished tiled surfaces, their cadence and step length decreased.

In unshod condition, the toddlers were seen to walk and stand with open toes (Fig 5). The heel strike was very little. In static position their body was not stable and they constantly kept moving and shifting their body weight from the left to the right leg.



**Fig 5 The unshod feet of a 26 month toddler showing wide spread toes for increased balance and grip**

Among the three surfaces that the toddlers walked on, namely grass, marbled floor and tiled floor, in unshod condition, stability was found to be the maximum on grass and least on the tiled floor. This could be

attributed to the fact that polished surfaces are prone to slippages which can be sensed by the feet and hence their manner of walking becomes more cautious and slow.

In shod condition the toddlers walked faster and avoided touching the ground with their heel. They toppled over more frequently as compared to unshod condition. Possible reason for longer stride in shoes includes that of an effective increase in leg length and also because of the increase in the mass of the shod foot. (Wegener.,2011). The increased frequency in falling of a shod toddler can be understood by the fact that no matter how flexible the sole of the footwear may be, the deceptively flexible sole is behind the metatarsal flex line across the foot which is in conflict with the foot’s normal flex line angle. Hence the toddler has higher chances of falling (Rossi, 2002).

The unstable gait is also attributed to the fact that the toddler has to carry that extra weight of the alien body restricting the foot that it is housed in. However light in weight the footwear be, it is an added weight to be borne by a toddler who is yet trying to form a gait and place the foot firmly on the ground.

**Design derivations**

The study shows the importance of footwear for healthy foot development. The research leads to various design directions for designing toddlers’ shoes. Early walkers are trying to form their individual gait pattern. Table 4 discusses various design decisions that have been derived from the analysis of the primary and secondary research for designing scientific footwear for toddlers, which can help maintain the normal gait of individuals.

*Table 4 Design Derivations from Secondary and Primary Research*

S. No	Conclusions from Secondary and Primary Research	Design Decisions
1	Toddlers keep moving their feet even in static position. For a particular foot length, the width can vary.	The footwear needs to have allowance of 0.5-0.8 cm on the sides. (Width wise)
2	Toddlers keep wiggling their toes	The footwear needs to be broad and have 1.2-1.5 cm space as toe room near the forefoot
3	There is constant shifting of pressure distribution from heel to the forefoot	Sole should be able to bear the load uniformly throughout. (*4-6 N/mm <sup>2</sup> )
4	Maximum pressure is on the heels.	Heels need to be cushioned and strengthened for balance and comfort.
5	Toddlers are not able to put the foot firmly on the ground	The material of the sole needs to be such that it avoids slippages. (*abrasion resistance volume loss: 150-250mm <sup>3</sup> )
6	Toddlers tend to lose balance while walking	The sole should be able to absorb shock and provide support and balance
7	Foot axis angle of left and right foot is different	The shoe needs to be soft and flexible to be able to conform to the natural shape of the foot.
8.	The toddlers tend to topple over easily when in shod condition	The sole should be very flexible and tractive to give support and balance to the toddler.
9.	Indian retail market does not cater to the starting size of Indian toddlers	The starting sizes for the Indian market needs to be reconsidered to start with inner length of 11 cm.
10.	There are varying feet width in a particular length of foot	Indian footwear should be available in at least three varying widths namely narrow (N), medium (M) and wide (W).

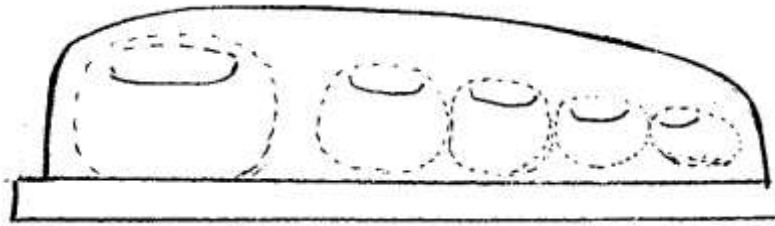
[\* according to the recommendation by Central leather Research Institute (CLRI)]

**Architectural derivations**

**Toe Shape**

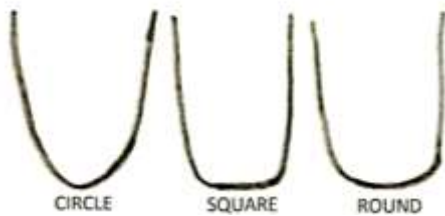
The toe shape of a shoe depends on the last selected for the design of the footwear. The toe shape is as important as the fit or the size of the shoe. A shoe with a narrow tread will fit differently as compared to a

shoe with square or a round tread if worn by the same individual.



**Fig 6 Broad Toe Shape of the Shoe Gives More Comfort and freedom of Movement to the Toes**

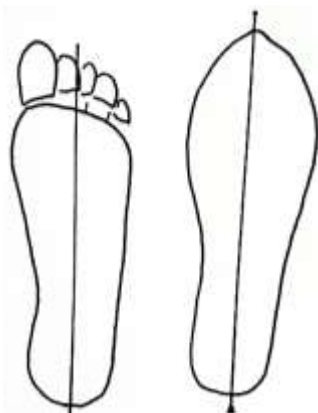
It is important to select a shape which gives maximum movement to the toes inside the shoe as the primary research shows that the toddlers keep wiggling their toes constantly inside the shoe (Fig 6). The recommended toe shapes for kids shoes are as shown in fig 7.



**Fig 7 Toe Shapes for Toddlers' Footwear**

**Last**

Last for the toddlers footwear should be based on the straight axis principle (Fig 8) as also supported by earlier studies by Staheli and Rossi. It is important that the footwear for toddlers should be as close as the shape of the natural foot itself and hence the last chosen should be a replica of the shape of the foot itself.

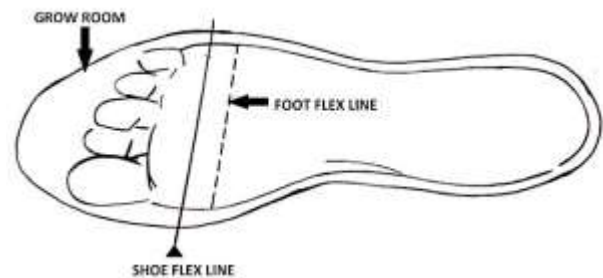


**Fig 8 Last Based on Straight Angle Axis Principle for Toddlers**

**Foot Length and Foot Width**

The foot length and the foot width vis a vis that of the footwear is important for the fit. Correct inner ball position is important not only for proper shoe fit but

also proper flex at ball. If too much grow room allowance is given, ball flex line is too far back creating flex conflict between shoe and foot.



**Fig 9 Flex Line of the Foot and The Footwear Should Match**

Various scales have been studied to establish the relation between the foot length and the last length and between the foot width and the last width.

According to the scales, toe room allowance in toddlers' shoes should be 1 1/2 sizes or half inch. The same will also depend upon the style of the last. According to the shoe design experts, 2/3<sup>rd</sup> inch built in size allowance is important which takes care of:

- 1) one full size for grow room
- 2) about half size for forward foot movement within the shoe
- 3) about half size for loss of original dimension of the shoe.

Shoe of a proper size should be able to slip in without any force or use of shoe horn.

Among toddlers a grow room of 12-15mm has been given which allows free movement of the toes.

Though the sizing scales consider the difference in the foot length and the toe, none of the scale, however, refers to the relation between the width of the foot and the last. According to Dr. Rossi, the width of the foot varies in different conditions like the foot at rest, the foot on weight bearing and the foot under thermal condition will have different widths.

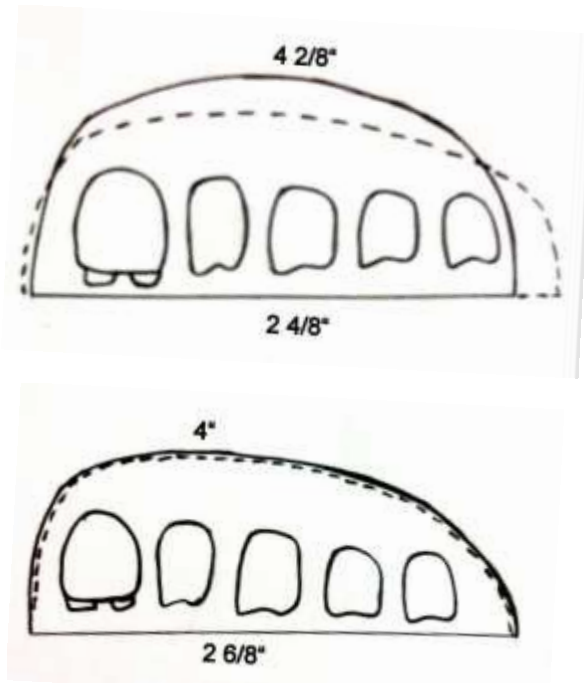


Fig 10

Designers of toddlers' footwear are dealing with a malleable, undeveloped foot. An improper width fit will be detrimental as the foot will tend to lose its balance due to improper tread, in a tight or a loose fitted shoe even if the length of the shoe fits properly. Figure 11 compares the fit of the shoe with different ball widths. Despite identical sizes the two shoes will fit differently. The width of the shoe should have 5-8 mm allowance for free movement of the toes and the foot at the ball.

#### Throat Line

It is important that the toddlers' footwear have a broad throat line to allow easy slippage of foot inside the shoe. Patterns with open flap at the throat (Fig 11) provide better throat fit than others as it allows space for growth and fit adjustment for sizes with different ball girth measurements.

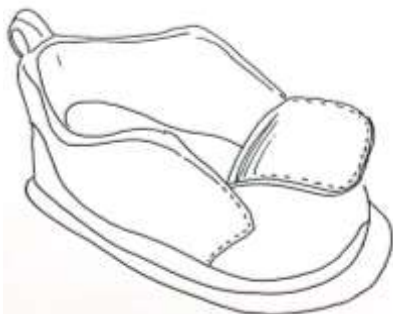


Fig 11 Shoe with Open Flap at Throat Line for easy slippage of the foot

#### Closures For the Toddlers' Shoes

Various closures are used commercially for the toddlers' footwear like laces, Velcro, zippers, buckles, snap buttons and tie ups. Analysis of the questionnaires distributed to the parents show that the main concern for the parents is that the toddler should not be able to remove the shoe on his own. Parents are also concerned about the ease of use of the closure, that they do not like to bend and that the closure should be such that the toddlers should be able to put on and take off their shoe without any help after a certain age. Though parents of early walkers prefer laces, however, the earlier studies show that laces should not be used for toddlers who are unable to comment on the degree of tightness on their tender feet. "Shoe lace imposes pressure on the dorsalis pedis artery restricting normal blood flow. Padded tongue provides a buffer zone against tight lacing, preventing entry of air or evaporation of foot moisture" (Rossi, 2002).

From among the other closures, primary research shows that Velcro is the most preferred closure due to the strength of holding the shoe and the ease of use. The toddlers above 30 months are also able to independently use the closure to put on or remove their shoes. Also Velcro do not have any metal or small plastic pieces which could be dangerous for the toddlers.

The strap placement for holding the Velcro also needs due consideration while designing patterns for the toddlers' shoes. The higher the strap placement the better is the grip of the shoe. A flexible shoe does not require much hold on power as compared to a rigid shoe.

#### Counter Stiffener

The purpose of the counter is not to support the heel of the foot but to give dimensional stability to the shoe at the back thereby lending support to the foot for balance and alignment in the forward direction. This makes the grip stronger and prevents heel slippages. In case of toddlers' footwear the patterns for the counter should be cut differently for the right and the left side of the foot to accommodate the different heights of the inner and outer ankle bones. This will provide better fit and render comfort to the wearer due to reduced chances of ankle rubbing.

#### Materials for Different Shoe Components

Selection of right kind of material is very crucial for development of scientific footwear for toddlers which is aimed to provide maximum comfort and normal gait. The commercially available materials in the market have been compared and tested against the

standards provided by Central Leather Research Institute (CLRI).

#### **Material for Outer Sole for Toddlers' Footwear**

Based on the architectural requirements, leather and rubber cannot be used as the soling materials for toddlers' footwear due to their weight, non- flexibility and inadequate traction. PVC, PU and TPR were then

sent for testing at SATRA Laboratory at Footwear Design and Development Institute, NOIDA. The results have been compared with the standard references taken from Central Leather Research Institute, Chennai and are as shown in Table 5.

**Table 5 Comparing Test Results of Different Materials for Soles**

<b>Materials</b>	<b>PVC</b>	<b>PU</b>	<b>TPR</b>
<b>Properties</b>			
Density	1.2 g/cc	0.43 g/cc	0.92 g/cc
CLRI Standard	1.20-1.27g/cc	Min 0.5g/cc	0.9-1g/cc
Abrasion Resistance, mm <sup>3</sup> Volume Loss	76 mm <sup>3</sup>	148 mm <sup>3</sup>	149 mm <sup>3</sup>
CLRI Standard	Max 250 mm <sup>3</sup>	Max 300 mm <sup>3</sup>	Max 350 mm <sup>3</sup>
Flexing Resistance	No cracks upto 30,000 flexes	No cracks upto 30,000 flexes	No cracks upto 30,000 flexes
CLRI Standard	Max 0.5mm/kc	No cracks upto 30,000 flexes	Max 0.1mm/kc
Weight	Heavy	Light	Light

PVC is hazardous to be used for sole for toddlers' footwear due to its carcinogenic properties. According to the footwear experts the polymer gets transmitted to the skin which makes it dangerous to be used for toddlers.

PU as a polymer has a shorter shelf life as it granulates. It is more expensive as compared to TPR and can be attached to the upper only by injection molding process, which is not widely used by Indian manufacturers.

Advantages of TPR were identified as

- Moderately tractive
- Does not decompose easily
- Has dimensional stability
- Is flexible
- Light in weight
- Safe for toddlers

Hence TPR was selected to be used as the soling material for the toddlers' footwear.

#### **Material For Shoe Upper For Toddlers Footwear**

Commercially there are three different materials used for the shoe uppers namely:

- a) Leather like sheep, cow, goat and buff
- b) Textiles like canvas, denim, corduroy, drill and knits

c) Manmade material like vinyls, urethanes and pomerics

Comparison in the properties of these materials show that leather and fabrics are suitable materials to be used as materials for shoe uppers for toddlers footwear as these are highly breathable and allow moisture transmission thus keeping the foot dry inside the shoe. Among leather and fabric the author has selected sheep napa since it is soft, supple, breathable and resilient, has good elasticity and is light weight.

#### **Material for Lining For Toddlers Footwear**

Like shoe uppers, lining can also be made from three materials namely leather crust, fabrics and manmade materials. These materials have been compared for the properties before the selection of the materials to be used for the prototype development.

1. Leather Crust- Properties include: natural, high moisture absorption capacity, provides insulation, easy to maintain, high on aesthetics
2. Textiles- natural, high moisture absorption capacity, thin, soft, provides good grip, anti static
3. Manmade Materials- artificial, poor moisture absorption, gives out odor on perspiration



Since the lining needs to be thin, soft, and high on vapor permeability, cotton fabric of 280 gsm was selected for the lining to be used for prototype of toddlers' footwear.

### Prototype Development

Two prototypes were developed as shown in Fig 12 & 13 according to the design and architectural derivations.



Fig: 12 Prototype I



Fig: 13 Prototype II

**Wear Trials**

Physical wear trials were conducted on 25 toddler with normal gait of footwear size 22 (girls 14) and 24 (boys 11) in the month of February/ March 2014, 25°C - 27°C, New Delhi, India. Questionnaires were handed to their mothers. The mother reported that the footwear was soft and hence more comfortable. The toddlers walked with increased ease in shod condition throughout the day. The feet remained almost dry after continuously using the footwear for 4 hours. (Dryness was tested with a tissue paper) and the toddlers did not fuss about removing the shoe in 4 hours.

The impact of the footwear on the gait of the toddler was scientifically measured using Pressure plate scanners. Readings were noted on 2 toddlers in shod and in unshod condition.

The results obtained showed that the gait in the shod condition was very near to the gait of the toddler in unshod condition. The pressure applied was seen to be as follows:

**Table 6 Results of wear Trials of Pressure applied on the feet during shod and unshod conditions**

Condition	Left Foot	Right Foot
Unshod	45.7%	54.3%
Shod	47.6%	52.4%

It was also noted that the points of maximum pressure applied by the toddler on the left and the right foot in natural unshod static condition showed a very negligible shift in the shod condition wearing the newly developed prototype.

**Conclusion**

Toddlers footwear is not just an accessory complimenting the dressing of an individual. It plays an important role of developing foot health and molding the shape of foot. The study was aimed at developing scientific footwear for toddlers for the Indian market that could help attain gait (in shod condition) as close as the natural gait of a toddler.

The study helped to derive certain design and architectural requirements for toddlers' footwear. The Indian market is unable to cater to the sizes of the early walkers with small feet. The domestic brands and manufacturers need to address the lacunae in this segment and need to add smaller foot lengths in the market. The variation in the feet width of individuals with same foot length indicates the need for introducing different last widths to cater to different shapes and widths of the feet.

The footwear for toddlers should be based on straight axis principle. The footwear for toddlers should be

comfortable, light weight, flexible, should have uppers and linings made from natural materials and should be of good fit. Good fit for footwear is defined as footwear which has enough space to accommodate the foot in static, dynamic, weightbearing and fatigue conditions. It should have room, length wise and width wise, to allow free movement of the toes within. A room length of 12-15 mm and width allowance of 5-8 mm has been seen to fit with comfort and ease among the toddlers giving adequate room for the toes to wiggle and foot to tread.

In order to attain maximum flexibility and natural movement of the foot, hard soles, mid soles and counter stiffeners should be avoided. The footwear should be broad and quadrangular allowing maximum comfort and movement of the toes. The sole of the shoe should be moderately tractive. i.e. the sole friction should be equivalent to bare foot.

India has a high rate of population suffering from problems arising due to ill-fitting shoes. The society needs to be made aware of the impact of ill-fitting footwear on the vulnerable feet at tender age (of toddlers) so that they do not have to undergo the trauma of being housed in wrong footwear.

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