The Research Journal of
the Costume Culture

pISSN 1226-0401 eISSN 2383-6334
RJCC Vol.24, No.3, pp.315-323, June 2016
http://dx.doi.org/10.7741/rjcc.2016.24.3.315

[Original Article]

3D printed midsole design according to the sole types of elementary school students

Ho Sun Lim†
Dept. of Clothing & Textiles, Sookmyung Women's University, Korea

Abstract

The present study is intended to study sole types necessary for shoe designs for elementary school students that are in age groups in growth periods, and 3D midsole design utilizing 3D printing technology. This study analyzed data from the 3D measurement of the feet of 1,227 elementary school students aged 7－13 years residing in the capital region conducted as part of the 6th Anthropometry of Size Korea. In addition, 3D midsoles by sole type were designed utilizing a Rhino CAD, and midsole prototypes were output utilizing a Zortrax-M200 3D Printer. Through a cluster analysis of sole shapes by type, sole shapes were classified into three types. Type 1 has small values of foot lengths and foot breadths, with large toe 1 angles and high arch heights. Type 2 has intermediate values of foot lengths and foot breadths, with small toe 1 angles and high arch heights. Type 3 has large values of foot lengths and foot breadths with small toe 1 angles and low arch heights. On reviewing the results of design of 3D midsoles by sole type, it can be seen that the midsoles were designed according to characteristics by sole type. The results of the sole type analysis in the present study are expected to be meaningful as basic data for the development of shoe insoles for elementary school students.

Keywords: 3D printing technology, sole shape, midsole, elementary school student, 3D scan

I. Introduction

Although overall recession has been persisting recently due to global economic recession and weak domestic demand, the scale of the kids industry has been continuously growing (Um, 2015) In addition, the children's clothing industry is also receiving attention as a blue ocean market (Park, 2015). Therefore, children's shoes should be studied and developed. In particular, since elementary school students are in a period of fast physical growth and wearing inadequate shoes in the growing period can adversely affect bone growth and foot shape changes, the development of shoes for children is important (Lee & Do, 2013; Markus, Dirk, Angela, & Robert, 2008). To review previous studies on foot measurement items of age groups in growth periods, Lee and Do (2014) analyzed the comparisons of sizes by item between genders and among school years through *t*-tests, ANOVA,

Received April 27, 2016
Accepted June 13, 2016

†Corresponding author
(lhs@sm.ac.kr)

ORCID
Hosun Lim
http://orcid.org/0000-0001-6649-9455

and Duncan post-hoc tests using data from the 3D foot measurement conducted on elementary school students in the 6th Anthropometry of Size Korea. According to the results, averages by item increased as ages increased in all items except for the item angles and higher index values were shown by male students compared to female students indicating that male students' feet were larger. Lee and Do (2013) conducted 2D indirect measurement of the feet of 310 female high school students in the Gwangju region using a flatbed scanner and analyzed the sole types through a factor analysis and a cluster analysis. As a result, five factors; lateral foot breadth protrusion, instep ankle breadth, medial foot breadth protrusion, ball line slope, and foot length and the feet were classified into three types. Park (2002) measured the feet of a total of 105 male and female first year elementary school student residing in the Daegu region and analyzed the characteristics of the growth of the feet and lower legs of first graders (1995, n=105), third graders (1997, n=105), and fifth graders (1999, n=78). Although foot measurement studies for age groups in growth periods including elementary school students and middle/high school students have been conducted as such, studies on the analysis of the sole types of elementary school students are insufficient.

In addition, since currently, ready-made shoes are produced only in sizes that are sold well, a large proportion of the populace is experiencing inconvenience because they cannot get shoes that fit their feet (Electronic Science, 2015) and some consumers cannot wear ready-made shoes because their feet are much larger or smaller than general foot sizes and have to wear custom-made shoes (Kang, 2009). Therefore, recently, customized shoe-making technologies utilizing 3D scanners and 3D printing technology have been actively developed.

The 3D printing technology that has become an hot issue throughout the world has been utilized in diverse industries and has been also utilized in the fashion field leading to new paradigms in fashion and 3D technologies. Among global sports brands, Nike and Adidas developed sport shoes utilizing 3D printers and released the shoes as products (Zaleski, 2015) and famous fashion designers have presented clothes made utilizing 3D printers in their fashion collections (Bodhani, 2014). In the research field, following this trend, studies on the fabrication of customized shoe lasts utilizing 3D foot scanning and 3D printers (Kim, 2013; Kim, 2014) and those on customized shoe midsoles (Kim & Jung, 2015) have been actively conducted. Accordingly, further studies on sole types are considered necessary to develop such shoes lasts, midsoles, and insoles using 3D printer.

Therefore, the present study is intended to study sole types necessary for shoe designs for elementary school students that are age groups in growth periods and 3D midsole design utilizing 3D printing technology.

Ⅱ. Methods

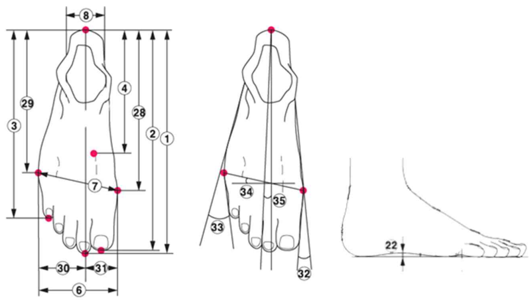
1. Sole type analysis

This study analyzed data from the 3D measurement of the feet of elementary school students aged 7 – 13 years residing in the capital region conducted from June 21 to December 18, 2011 as part of the 6th Anthropometry of Size Korea. Out of the foot measurement data from a total of 1238 students, data from 1227 students were used in the analysis excluding data from 11 students which were incomplete. Based on previous studies (Lee & Do, 2013), 16 items; foot length, heel-to-toe 1 length, heel-to-toe 5 length, heel-to-instep length, foot breadth, ball distance, heel width, arch height, heel-to-tibiale length, heel-to-fibulare length, medial ball width, lateral ball width, toe 1 angle, toe 5 angle, ball line angle, ball center line angle that correspond to sole related measurement items for midsole design among 35 foot measurement items of Size Korea were analyzed. The foot measurement reference points and measurement items are as shown in 〈Fig. 1〉 and 〈Table 1〉.

In the present study, the factor analyses were conducted to derive the constituting factors of the sole types of elementary school students and the cluster analyses were conducted to classify the sole types. In addition, ANOVA and Duncan posteriori tests were conducted to examine differences among the classified types.

2. 3D printed midsole design

For 3D midsole designing, 3D CAD modeling was conducted utilizing the Rhino program. Based on previous studies (Chung & Lee, 1996; Hwang, Kim, & Park, 2003; Kim & Kim, 2011), the foot length, foot breadth, and arch height that have important effects on the fabrication of midsoles were basically determined and other foot sizes were applied to design midsole designs by the sole type of elementary school students.

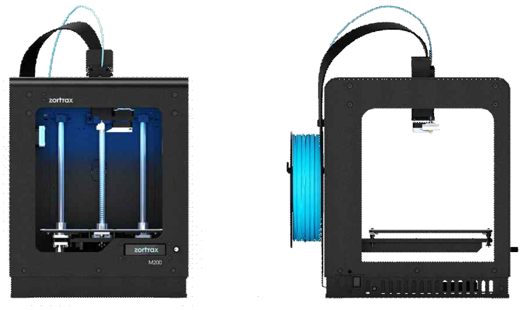


<Fig. 1> 3D foot measurement items for sole types
From. Korean Agency for Technology and Standards. (2011). p.85.

<Table 1> Foot measurement items for sole types

No.	Items	No.	Items
1	Foot length	28	Heel-to-tibiale length
2	Heel-to-toe 1 length	29	Heel-to-fibulare length
3	Heel-to-toe 5 length	30	Medial ball width
4	Heel-to-instep length	31	Lateral ball width
6	Foot breadth	32	Toe 1 angle
7	Ball distance	33	Toe 5 angle
8	Heel width	34	Ball line angle
22	Arch height	35	Center line angle

From. Korean Agency for Technology and Standards (2011). pp.83-84.



<Fig. 2> Zortrax-M200 3D Printer
From. Dream 3D (2016). https://www.dream3d.co.uk

<Table 2> Specifications of Zortrax-M200

Specifications	
Technology	LPD (Layer Plastic Deposition)
Build volume	200×200×185 mm
Resolution of single printable point	400+ microns
Filament type	Z-Filaments™
Filament diameter	1.75 mm (0.069 in)
Minimum single positioning	1.5 microns
Positioning precision (X/Y)	1.5 microns
Z-axis single step	1.25 microns

From. Dream 3D (2016). https://www.dream3d.co.uk

In addition, based on a previous study (Kim, 2013; Kim & Jung, 2015; Park & Kim, 2005; Park, Lee, Kim, Yoo, & Kim, 2011), some extra spaces were given to the foot lengths by adding 10 – 15 mm to the toe room and 0 – 5 mm to the heel and 6% was reduced from the foot breadth to design the outlines of midsoles. Then, prototypes of midsoles were output from the 3D modeling files utilizing a Zortrax-M200 3D printer as shown in 〈Fig. 2〉 and 〈Table 2〉.

Ⅲ. Results and Discussion

1. Composing factors of sole types

Factor analyses were conducted to extract factors that are related to the shapes of the soles of male and female elementary school students. When orthogonal

<Table 3> Factor analysis results of sole types

Items \ Factor	1	2	3	4
Foot length	.97	－.04	.04	.01
Heel-to-toe 1 length	.97	－.05	.03	.01
Heel-to-toe 5 length	.96	.03	.13	.00
Heel-to-tibiale length	.95	－.07	－.10	.01
Foot breadth	.94	.12	.03	.06
Ball distance	.94	.10	－.10	.06
Heel-to-fibulare length	.91	.00	.24	.00
Heel-to-instep length	.91	.00	－.03	.01
Heel width	.82	－.11	－.18	－.02
Medial ball width	.77	－.54	－.02	.06
Center line angle	－.13	.93	.06	.01
Lateral ball width	.65	.69	.07	.04
Ball line angle	.08	－.14	－.81	.01
Arch height	.08	－.05	.72	.07
Toe 1 angle	.02	－.13	.08	.78
Toe 5 angle	.02	.14	－.01	.77
	Length-breadth	Foot centerline toe lateral side	Arch height	Toe angles
Eigenvalue	8.83	1.75	1.33	1.22
Variance (%)	55.21	10.95	8.29	7.63
Accumulative variance (%)	55.21	66.16	74.45	82.08

Varimax rotation was used, four factors with eigenvalues not smaller than 1 were extracted and these factors explained 74.65% of the entire variance. 〈Table 3〉 shows the factor loadings of individual factors extracted through the factor analyses. The characteristics of individual factors are reviewed as follows. Factor 1 is a foot length and breadth factor and the contribution ratio was shown to be 55.21%. Factor 2 is a factor for the foot centerline and the lateral side of the toes and the contribution ratio was shown to be 10.95%. Factor 3 is a factor that is involved in arch heights and the contribution ratio was shown to be 8.29%. Factor 4 is a factor that affect toe angles and the contribution ratio was shown to be 7.63%.

2. Typing of sole shapes

To classify sole shapes by type, cluster analyses were conducted using the individual factors extracted through the factor analyses as independent variables. According to the results, the characteristics of sole shapes appeared the most clearly when the number of clusters was three. To review the distribution of the three types, type 1 was the most densely distributed as the number of type 1 was 600 (48.9%), the number of type 2 was 329 (26.8%), and the number of type 3 was 298 (24.3%). ANOVA was conducted to examine whether the four factors derived through the factor analyses were statistically significantly different among the three types and Duncan tests were conducted as post-hoc tests. According to the results, all factors showed significant differences as shown in 〈Table 4〉. In addition, ANOVA was conducted to examine the

<Table 4> ANOVA results of factor scores by sole types

Factors \ Types	Type 1 (n=600)	Type 2 (n=329)	Type 3 (n=298)	*F*-value
Factor 1	-0.472 C	0.032 B	0.907 A	273.210***
Factor 2	-0.555 C	1.146 A	-0.156 B	635.094***
Factor 3	0.216 A	0.304 A	-0.775 B	146.512***
Factor 4	0.077 A	-0.041 AB	-0.119 B	4.181*

Duncan test: A>B>C
***p<.001, *p<.05

characteristics of foot size measurement items by type and Duncan tests were conducted as post-hoc tests. According to the results, all measurement items showed significant differences except for the item Toe 5 angle as shown in 〈Table 5〉. The characteristics by type are reviewed as follows.

Type 1 showed the lowest averages of actually measured values of length items comprising foot length, heel-to-toe 1 length, heel-to-toe 5 length, heel-to-tibiale length, heel-to-fibulare length, and heel-to-instep length and breadth items comprising foot breadth, ball dis-

<Table 5> ANOVA results of measured foot dimensions by sole types

Factors	Items \ Types	Type 1 (n=600)	Type 2 (n=329)	Type 3 (n=298)	Total (N=1227)	*F*-value
Factor 1 Length-breadth	Foot length	204.19 C	211.97 B	227.33 A	211.92	225.26***
	Heel-to-toe 1 length	203.93 C	211.42 B	227.09 A	211.58	226.94***
	Heel-to-toe 5 length	167.41 C	175.50 B	184.95 A	173.84	183.37***
	Heel-to-tibiale length	148.24 C	153.14 B	166.92 A	154.12	276.28***
	Foot breadth	77.29 C	82.41 B	87.05 A	81.06	239.94***
	Ball distance	79.47 C	84.32 B	90.57 A	83.49	304.43***
	Heel-to-fibulare length	130.49 C	136.45 B	142.60 A	135.08	116.10***
	Heel-to-instep length	122.38 C	127.92 B	138.79 A	127.87	220.88***
	Heel width	55.72 C	56.80 B	62.78 A	57.73	246.23***
	Medial ball width	37.38 B	34.73 C	41.38 A	37.64	195.03***
Factor 2 Foot centerline toe lateral side	Ball center line angle	0.94 B	2.52 A	1.02 B	1.38	506.06***
	Lateral ball width	39.80 C	47.40 A	45.45 B	43.23	515.99***
Factor 3 Arch height	Ball line angle	13.40 B	12.68 C	16.34 A	13.91	112.61***
	Arch height	13.91 A	14.31 A	11.15 B	13.34	55.91***
Factor 4 Toe angles	Toe 1 angle	6.55 A	4.93 B	4.86 B	5.71	14.14***
	Toe 5 angle	9.79 A	11.22 A	9.73 A	10.18	2.51

Duncan test: A>B>C
***p<.001

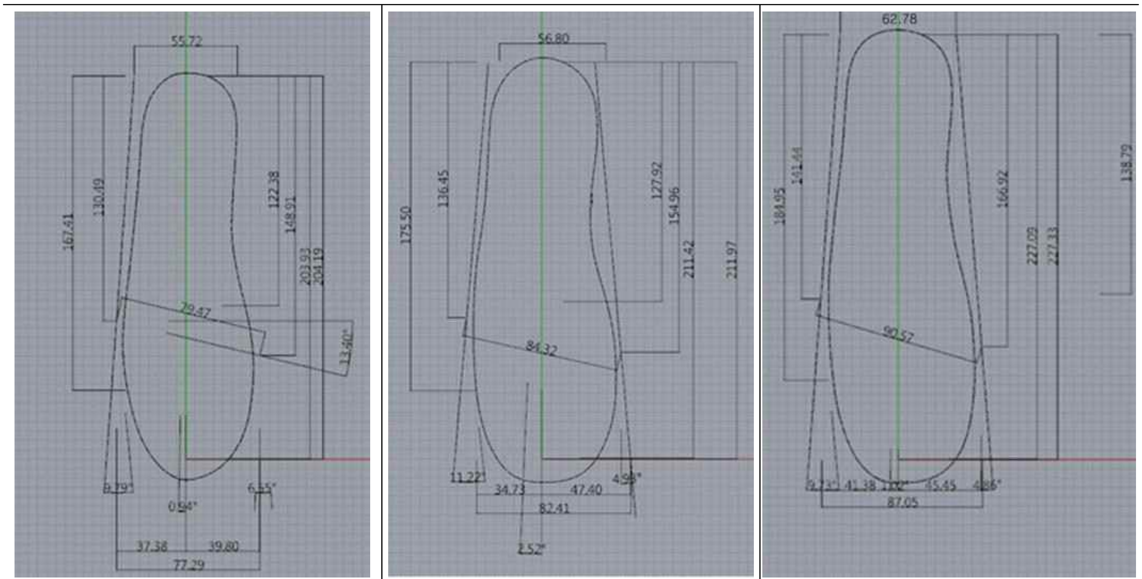
tance, and heel width. In addition, type 1 showed small values of ball center line angles and lateral ball widths while showing large values of arch heights and toe 1 angles. Type 2 showed intermediate averages of actually measured values of length items comprising foot length, heel-to-toe 1 length, heel-to-toe 5 length, heel-to-tibiale length, heel-to-fibulare length, and heel-to-instep length and breadth items comprising foot breadth, ball distance, and heel width. In addition, type 2 showed large values of ball center line angle, lateral ball width, and arch height while showing relatively small values of toe 1 angles. Type 3 showed the highest averages of actually measured values of length items comprising foot length, heel-to-toe 1 length, heel-to-toe 5 length, heel-to-tibiale length, heel-to-fibulare length, and heel-to-instep length and breadth items comprising foot breadth, ball distance, and heel width. In addition, type 3 showed intermediate lateral ball widths and relatively small ball center line angles, arch heights, and toe 1 angles. As shown in 〈Table 5〉, in relation to the items foot length and breadth, the sizes of type 2 showed a tendency to be similar to the whole average sizes.

3. 3D printed midsole design

The results of design of 2D midsole utilizing the Rhino CAD are as shown in 〈Fig. 3〉. As can be seen in 〈Fig. 3〉, after designing 2D midsoles by sole type by applying average sizes by item, based on previous studies for midsole design, some extra spaces were given to the foot lengths by adding 12 mm to the toe room and 2 mm to the heel and 6% was reduced from the foot breadth to design the outlines of midsoles.

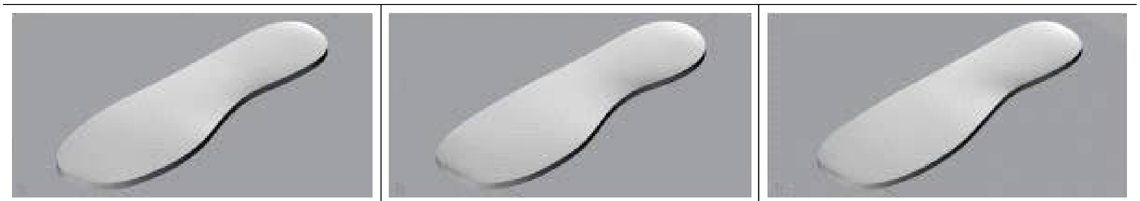
In addition, arch height measurements by sole type were applied and a midsole thickness of 5mm for all types were applied to design 3D midsoles by sole type and the results are as shown in 〈Fig. 4〉.

On reviewing the results of design of 2D and 3D midsoles by sole type as described above, it can be seen that the midsoles were designed according to characteristics by sole type. That is, type 3 was shown to have been designed to have larger foot lengths and breadths while having smaller arch heights and toe 1 angles compared to other types. In addition, type 1 was shown to have smaller foot lengths and breadths while having larger arch heights with a form of the toes pointed on center compared to other types.



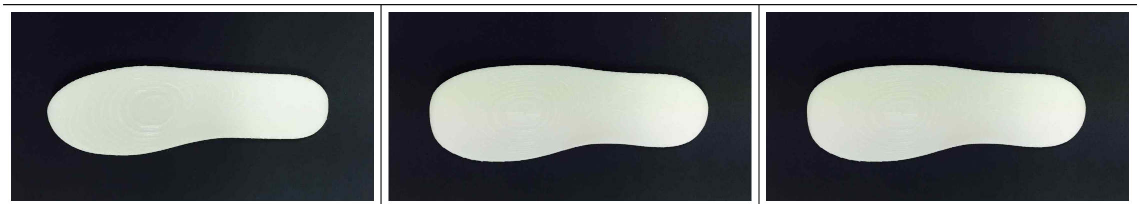
Type 1	Type 2	Type 3

<Fig. 3> 2D midsole designs by sole type



Type 1	Type 2	Type 3

<Fig. 4> 3D midsole designs by sole type



Type 1	Type 2	Type 3

<Fig. 5> 3D printed midsole prototypes

The midsoles by type designed in the Rhino CAD were saved as OBJ files which are compatible with 3D printers and midsole prototypes by sole type were output utilizing a Zortrax-M200 3D Printer. The results are as shown in 〈Fig. 5〉. The production of shoe midsole utilizing molding methods requires large amounts of cost and time. Therefore, the present study is intended to propose midsole design utilizing 3D printing technology as such that will enable making diverse prototypes of midsoles as samples before making actual midsoles as a way that can be utilized to reduce the cost and time spent when molds are made.

Ⅳ. Conclusion

In the present study, the sole shapes of male and female elementary school students aged 7－13 years were classified into types and the characteristics of individual types were analyzed. The results are as follows. Through a factor analysis of measurement items of the soles of male and female elementary school students, four factors were extracted; foot length breadth factor, foot centerline toe lateral side factor, arch height factor, and toe angle factor. Through a cluster analysis of sole shapes by type, sole shapes were classified into three types and distribution of the sole shapes of 600 (48.9%) in type 1, 329 (26.8%) in type 2, and 298 (24.3%) in type 3 was shown. Type 1 has small values of foot lengths and foot breadths with large toe 1 angles and high arch heights. Type 2 has intermediate values of foot lengths and foot breadths with small toe 1 angles and high arch heights. Type 3 has large values of foot lengths and foot breadths with small toe 1 angles and low arch heights.

As shown by the above results, the type with large values of foot lengths and foot breadths tended to show lower arch heights compared to other types. In addition, it could be seen that, in the case of male and female elementary school students' sole shapes, not only foot length and foot breadth items but also other factors such as toe lateral breadths, toe 1 angles, and arch heights affected type classification.

The results of the sole type analysis in present study are expected to be meaningful as basic data for the development of shoe insoles for elementary school students. The present study regarding the production of midsole prototypes utilizing 3D CAD and 3D printing technologies is expected to be meaningful as a way that can be utilized to reduce the cost and time spent to design and make diverse midsoles. However, this study has a limitation that only prototypes of midsoles were developed due to limited 3D printer materials. Follow-up studies on 3D printed midsoles utilizing midsole materials that can be actually commercialized are considered necessary.

References

Bodhani, A. (2014, December 15). 3D printing: fashion enters the technosensual era. *Engineering and Technology Magazine*. Retrieved April 10, 2016, from http://eandt.theiet.org/magazine/2014/12/from-computer-to-catwalk.cfm.

Chung, M. S., & Lee, Y. D. (1996). Measurements of the foot in Korean adolescents. *Ajou Medical Journal*, *1*(1), 268-275.

Dream3D. (2016). Zortrax M200 + Door and Side Covers. *Dream3D*, Retrieved May 30, 2016, from https://www.dream3d.co.uk/product/zortrax-m200

Electronic Science. (2015, July 22). ETRI, ICT 이용해 맞춤구두 제작한다 [ETRI, Manufactures customized shoes using ICT]. *Electronic Science*, Retrieved June 3, 2016, from http://www.elec4.co.kr/article/articleView.asp?idx=10276

Hwang, I. K., Kim, J. H., & Park, S. B. (2003). Foot change by a period of time for last production. *Proceeding of Korea Industrial and Systems Engineering*, *1*, 119-122.

Kang, D. W. (2009, June 11). 구두 전문 쇼핑몰 슈자이너 [Shoes designer; a shopping mall specialized in shoes]. *Edaily*, Retrieved June 3, 2016, from http://www.edaily.co.kr/news/NewsRead.edy?DCD=A606&newsid=01892566589720736&OutLnkChk=Y

Kim, H. G. (2013). Manufacturing of customized handmade through establishment of 3D scanning database and 3D modeling: With focus on analysis of current industrial status and means of commercialization. *Journal of Digital Design*, *13*(1), 701-711.

Kim, H. G. (2014). Manufacturing of customized handmade shoes using 3-dimensional scanner: With focus on hallux valgus patients. *Journal of Digital Design*, *14*(1), 343-351.

Kim, J. H., & Jung, E. C. (2015). Modeling process development for customized woman midsole design based-on 3D printing technology: Focused on a women in her twenties with 235-240 mm foot size. *Journal of Korea Design Forum*, *48*, 267-277.

Kim, S. H., & Kim, H. S. (2011). Classification of foot types for a shoes size system for women in their 20~30s according to a survey of hand-made shoes companies. *The Costume Culture Association*, *19*(4), 876-887.

Korean Agency for Technology and Standards. (2011). 제6차 한국인 인체치수 3차원형상측정 조사사업 [3D body shape measurement project report of the 6th Size Korea project]. *Size Korea*, Retrieved March 9, 2016, from http://sizekorea.kats.go.kr/02_data/outline.asp

Lee, J. E., & Do, W. H. (2013). A study of foot growth of elementary school students. Proceedings of The Society of Fashion & Textile Industry, Fall Conference. Korea, 377.

Lee, J. E., & Do, W. H. (2013). Classification of sole types for female high school students by 2D scan data. *Fashion and Textile Research Journal*, *15*(6), 977-984. 977-984. doi:10.5805/SFTI.2013.15.6.977

Lee, J. E., & Do, W. H. (2014). A study of elementary school students' feet growth by 3D scan data. *Fashion and Textile Research Journal*, *16*(6), 935-944. doi:10.5805/SFTI.2014.16.6.935

Markus, W., Dirk, H., Angela, S., & Robert, M. (2008). Children sport shoes-A systematic review of current literature. *Foot and Ankle Surgery*, *14*(4), 180-189. doi:10.1016/j.fas.2008.04.001

Park, I. D., & Kim, S. K. (2005). Three dimensional last data generation system utilizing cross sectional free form deformation. *Journal of Institute of Control Robotics and Systems*, *11*(9), 768-773.

Park, M. A. (2002). A study on the character for the foot and calf growth of primary school children. *Fashion and Textile Research Journal*, *4*(2), 163-168.

Park, S. B., Lee, K. D., Kim, D. W., Yoo, J. H., & Kim, K. H. (2011). Comparative analysis of foot pressure distribution by functional insole to be transformed and restored during walking. *Korean Journal of Sport Biomechanics*, *21*(2), 231-241.

Park, S. H. (2015, October 20). 아동복, 중국 패션시장 블루오션으로 부상 [Children's wear, Chinese fashion market is emerging as the blue ocean]. *Fashion Insight*, Retrieved April 29, 2016, from http://www.fi.co.kr/main/view.asp?SectionStr=China&idx=52417&NewsDate=2015-10-05

Um, H. Y. (2015, March 16). 저출산 걱정인 정부와 불황 없는 키즈 산업: 너도나도 아이 모시기 [The government that worries about the low fertility and the kids industry with no recession: Everybody tries to attract children]. *Dream Maker*, Retrieved May 3, 2016, from http://www.dreammaker.media/?p=1006

Zaleski, A. (2015, December 15). Who's winning the 3D-printed shoe race?. *Fortune*. Retrieved March 23, 2016, from http://fortune.com/2015/12/15/3d-printed-shoe-race