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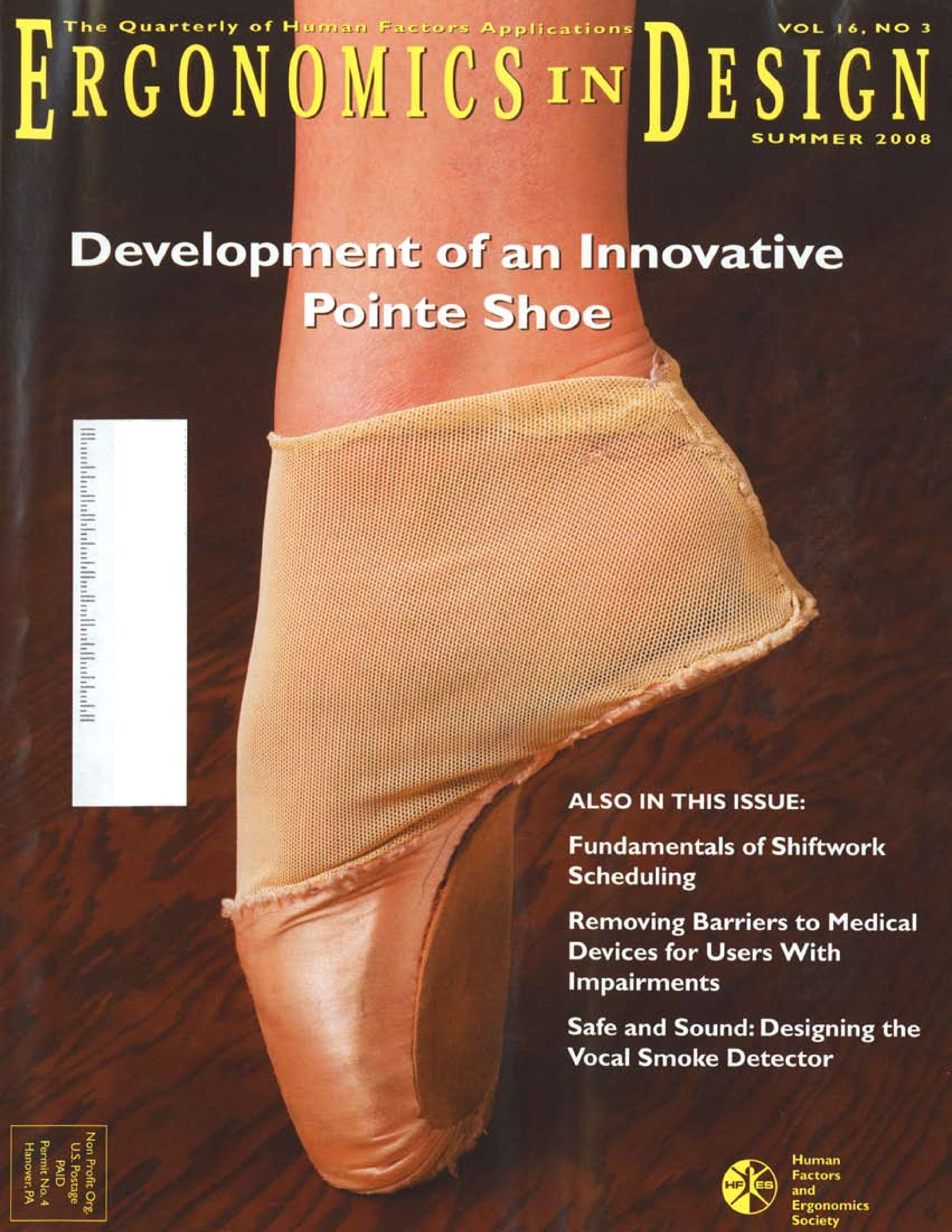

Development of an Innovative Pointe Shoe

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Development of an Innovative Pointe Shoe

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A fresh perspective is offered on the design of a piece of equipment that has undergone minimal modernization since its introduction in the early 19th century.

IT IS SAID THAT THE BALLET TOE SHOE IS one of the few instruments of torture that has survived intact to the present day. The toe, or pointe, shoe was first developed in 1832, and its introduction to ballet permitted ballerinas to rise on the tips of their toes and seemingly float across the stage (Kippen, 2004). In the early 1800s, Marie Taglioni broke all previous barriers of ballet by being the first ballerina to dance on her toes (Kippen, 2004). Toe dancing not only expanded the possibilities for ballet but, over time, became in itself an artistic expression.

At the most basic level, the pointe shoe is a tool, a very specialized piece of work equipment equivalent to an astronaut's suit, a surgical instrument, or a command and control display. However, the pointe shoe – veiled by its association with beauty and art – has been completely overlooked by ergonomists. Although lights, costumes, and staging of ballets have seen great innovation over the years, ballerinas are still dancing on a piece of cardboard hardened with glue (see Figure 1).

Hundreds of injuries and bone deformities are brought about by the pointe shoe's primitive design (Cleveland Clinic, 2005; Gaynor Minden, 2005). Among the reasons for this lack of innovation in toe shoe design is the belief that in ballet, discomfort and pain are silent parts of the backstage world that should not be brought to public attention (Gaynor Minden, 2005). For this reason, the pain related to pointe shoes has been ignored until the present day. A ballerina's shoe is an extension of her body and is intimately related to her dancing (Gaynor Minden, 2005).

FEATURE AT A GLANCE: In the range of specialized work equipment, pointe shoes occupy a special place. The design of these essential tools for dancers has remained essentially unchanged for 200 years. In an age of high-tech sneakers, pointe shoes are made of cardboard, newspaper, fabric, and glue and cause countless injuries and tremendous pain to ballerinas. In this project, we consider them in an ergonomic and usability context and explore design changes to improve their safety, comfort, usability, and durability.

KEYWORDS: ballet, ballerina, ergonomics, design, toe shoe

As ballerinas demand more from their shoes, it is time to reconsider these primitive objects in light of ergonomics principles and human factors guidelines. The goal of the project reported in this article was to identify ways to improve the performance, comfort, and safety of pointe shoes. By better understanding how pointe shoes are used, we pinpointed the ways in which they do or don't support dancers' needs. We then used these data to generate concepts for new designs and to develop initial prototypes of the most promising ideas.

Objectives of Our Research

The first objective of this research was to conduct an exploratory examination of the ergonomic and design factors of the pointe shoe. Although copious research has been done on many professional tools (for example, office chairs, cockpits, and hearing protection have each generated many volumes of analysis), little research has examined how pointe shoes are used, what are the needs of dancers, and how the shoe design can best serve those needs.

Although lights, costumes, and staging of ballets have seen great innovation over the years, ballerinas are still dancing on a piece of cardboard hardened with glue.

The second objective was to take a design perspective on pointe shoes: Are there new materials and design techniques that could be used to create concepts that begin to address the needs identified?

Figure 1. Interior of the pointe shoe: Within the pink satin cover lie layers of burlap and paper hardened with glue.

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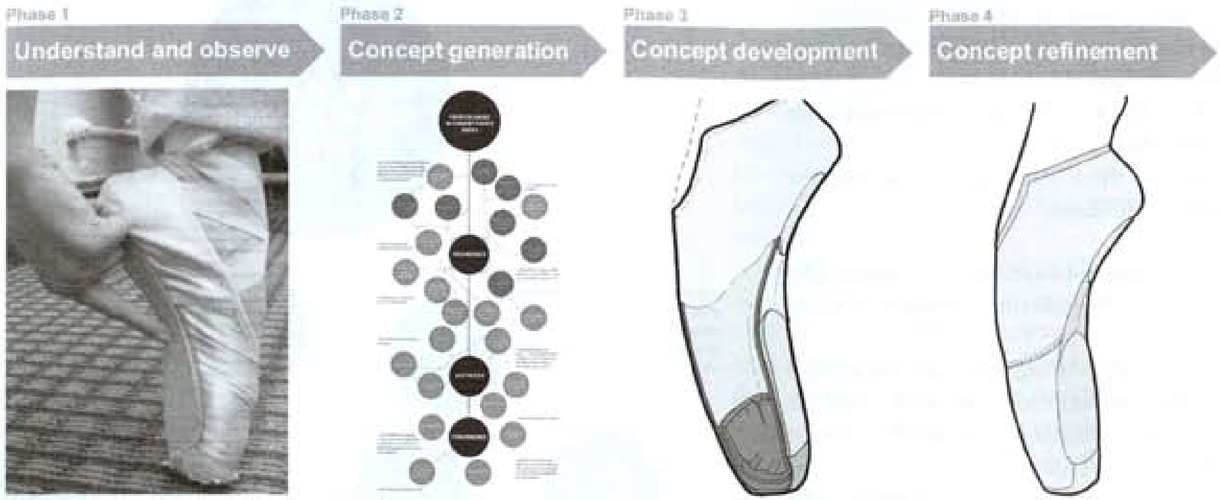

Figure 2. Flowchart outlining phases of the project.

The third objective was to explore whether prototyping these new concepts was possible or feasible and could lead to designs that address users' needs. Each objective was addressed in one of the four phases of the project (see Figure 2).

Method

We conducted interviews and observational research of pointe shoes in this study. We gathered information from 29 ballerinas either through personal interviews or via e-mail questionnaires. The research was conducted at locations throughout Boston with preprofessional and professional ballerinas and teachers who were trained at Boston Ballet, School of American Ballet, Nutmeg Conservatory, Lexington School of Ballet, Central Pennsylvania Ballet, José Mateo Ballet Theatre, and other schools in the region.

Dancers were asked to relate their pointe shoe experiences, their dislikes about pointe, their preparation of the shoes, and the characteristics of the ideal pointe shoe (for definitions of terms, see Grant, 1982). During the interviews, dancers performed the following actions:

- demonstrated putting on and taking off pointe shoes;
- demonstrated standing flat and on *relevé* (a raising of the body on the points or demi-pointes) while wearing pointe shoes;
- performed simple steps *en pointe*, (that is, *pas de bourree*, a traveling step in which the dancer picks up first one leg and then the other to either a low, medium, or high position, *rond de jambe* (a circular movement of the leg), *retire* (a position in which one leg is bent so that the pointed

Table 1. Parts of the Feet, Corresponding Part of the Shoe, and Potential Injuries

Parts of the Foot	Part of the Shoe	Description	Examples of Injuries
Toes	Platform	Tip of the shoe	Callus and corns – the buildup of hard skin with an accumulation of keratin in the epidermis. The direct result of pressure, stress, or friction, combined with abnormal foot mechanics.
Toes and metatarsal	Box	Encases dancer's toes	Bunions – an overgrowth of bone on the head of the first metatarsal. Primarily caused by improper biomechanics.
Arch	Shank	Supportive sole of the shoe	Plantar fasciitis – an inflammation of the fascia band (long ligament on bottom of foot). Two major causes are biomechanical conditions and trauma.
Whole foot	Quarter	Fabric that holds shoe on the foot	Tendinitis – an inflammation of the tendon. Commonly occurs in dancers in the Achilles tendon. May be caused/aggravated by excessively tight ribbons.

toe rests in front of, behind, or to the side of the supporting knee), *relevé* in various positions, and so on;

- talked about their past experiences with pointe shoes; and
- described their breaking-in procedure for new pointe shoes.

Interviews were documented with photographs that captured the ballerina–pointe shoe interaction.

Additionally, during this phase, we studied human foot anatomy to better understand the physical requirements of a pointe shoe design (see Table 1 and Figure 3).

Old pointe shoes were dissected and their structure, materials, and composition studied. We did extensive online research to learn about current innovations in ballet equipment. Photos of pointe shoes during use were examined to determine key stress points and areas of anatomical challenge. We then analyzed the interviews to better understand both the explicit and implicit needs of dancers, as revealed in the way they verbalized their desires for a new pointe shoe and demonstrated their processes while using the shoes.

Results

To analyze the results of these interviews, we created a concept map (see Figure 4). Each interview was reviewed and the issues for each participant were coded by hand. Then, the set of all issues was analyzed. Issues were grouped by theme around the major areas of ergonomics, aesthetics, and convenience. These areas emerged organically, bottom up from the data, not from a priori hypotheses.

Within each major area, smaller clusters were also formed to highlight more specific needs: for example, the desire for a shoe that hugs the arch of the foot, provides support when rising up to pointe, is durable, is quiet, and looks nice on the foot in any position. These more specific needs were used to drive decisions about where to focus the design efforts, what to solve, and how to start thinking about design solutions.

One finding of our background research was that although there have

Figure 3. Front view of foot muscles.

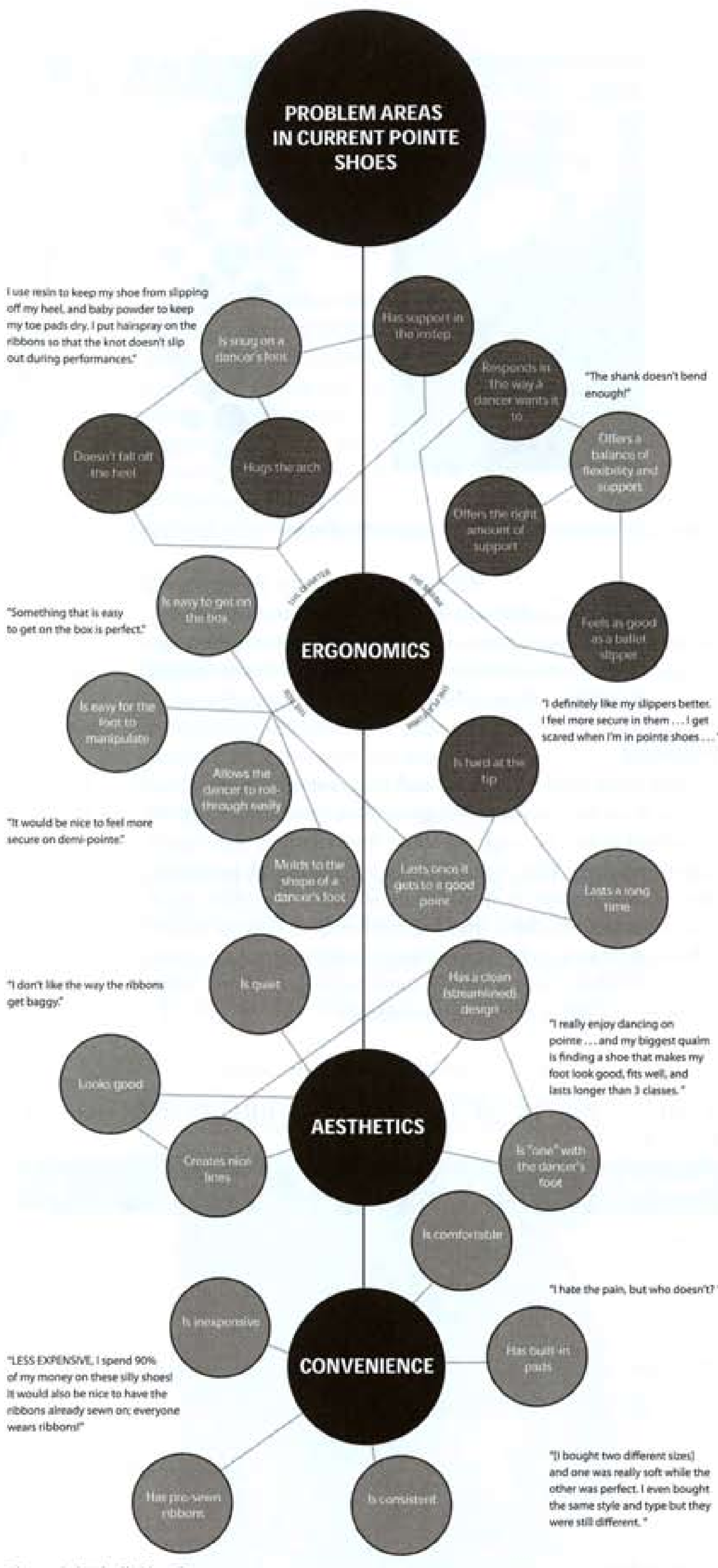

Figure 4. Conceptual diagram illustrating research results. Organized by problem area with specific issues that are encompassed in each area.

Figure 5. Parts of a pointe shoe and their equivalent counterparts on a running shoe.

been studies about the impact of pointe shoes on the human body and the effectiveness of current pointe shoe materials (see Cunningham, DiStefano, Kirjanov, Levine, & Schon, 1998), there has been only one marketed attempt to completely innovate the pointe shoe itself. These shoes, Gaynor Mindens, are promoted as having an unbreakable shank, as they are made of elastomerics (Gaynor Minden, 2005). Our research showed that this is not a quality ballerinas look for in their shoes.

Design

We used this understanding of user needs as the starting point for design, beginning with concept generation. Our initial focus was on the themes of ergonomics, aesthetics, and convenience. To be accepted, an innovative shoe has to address issues in these categories. Our design focused on four main areas of the shoe: the box, the platform, the shank, and the quarter (see Figure 5), with at least one major modification made to each (see Table 2, page 10). The changes we made are discussed next.

Materials. A variety of materials – among them titanium, polyurethane, and carbon fiber – were studied for the box and the shank. Titanium, used in high-end cars and bicycles, interested us because it is rigid and lightweight. However, it is very expensive. Carbon fiber is also rigid and can be very thin and light but is also expensive. Polyurethane can be stiff if molded in a high hardness, but the wall thickness is very high, probably exceeding the needs of this application. Tempered steel, commonly used in springs, is very low in cost but doesn't have adequate shock absorption. For covering materials, Dupont Tyvek® was explored because it is strong and easy to cut.

The platform. The platform is the flat area on the tip of the shoe where the dancer balances when *en pointe*. Because it is in constant contact with the floor and receives the most wear, the platform must be covered with a strong material that will adequately adhere to the floor. Tyvek slides easily and is stronger than satin (the material covering current pointe shoes).

Additionally, we looked at platform inclination. The most favorable inclination was between a 90° angle and leaning toward the shank. This inclination provides stable support when the dancer is fully stretched *en pointe* (see Figure 6, imagery from Ashley, 2004; Goh, 2005) and allows for easy transitioning when the dancer transfers her body weight.

The box. The box, one of the most important parts of the shoe, determines fit and comfort, the two top criteria a dancer considers when purchasing a pointe shoe (see Cunningham et al., 1998). An improperly fit box can cause injuries such as hallux valgus, a common deformation (also known as bunions). In conventional pointe shoes, the box interior is flat, but pointed toes do not form a straight line. The result is that the longest toe, usually the hallux, supports the majority of the body's weight (see Figure 7, page 10).

> Our design focused on four main areas of the shoe: the box, the platform, the shank, and the quarter, with at least one major modification made to each.

In the human anatomy, bone alignment is never perfect; there is generally a slight angle between the proximal phalange and metatarsal bone of the hallux (Spilken, 1990). As tremendous weight and pressure are added to these bones, the angle between them tends to increase, leading to hallux valgus (see Figure 7). All ballerinas who engage in pointe work have at least some degree of hallux valgus (Braver, 2005). The deformation can lead to arthritis and chronic pain as the condition worsens (Spilken, 1990). The leading cause of hallux valgus

Figure 6. A foot en pointe.

TABLE 2. PARTS OF THE FEET AND SHOE, AND DESIGN CONCEPTS

Parts of the Foot	Part of Shoe	Description	Needs	Design Concepts
Toes	Platform	Tip of the shoe	Durability, rigidity, stability: Endures most contact with the floor, the area on which a dancer will balance.	Study of best platform inclination to maximize stability and transition efficiency.
Toes and metatarsal	Box	Encases dancer's toes	Rigidity along sagittal (side-to-side) plane: Provides controlled flexibility along transverse plane.	Line interior with memory foam. Make box and shank one piece (see "Arch").
Arch	Shank	Supportive sole of the shoe	Rigidity along sagittal (side-to-side) plane: Provides controlled flexibility along transverse plane; gives dancer arch support so that she may balance.	Box-shank combination with differential areas of support. Designed with anatomical build in mind.
Whole foot	Quarter	Fabric that holds shoe on the foot	Must fit like a second skin over dancer's feet; keeps all parts of the shoe snug to ballerina's feet.	Boot shoe. Quarter made of elastic material that fits like second skin.

is improper biomechanics. When the dancer is *en pointe*, the shoe should facilitate proper alignment (Kippen, 2004).

The first proposed change for the box was to add a lining of memory foam to the interior to support each toe from underneath, thereby distributing the dancer's weight more evenly throughout the foot and decreasing pressure on the hallux. Another problem ballerinas expressed was forgetting to bring toe pads for class, which meant they would have to place raw skin on hard plaster. Built-in memory-foam pads would eliminate this problem. In general, the memory-foam lining promotes comfort, personalized fit, and better biomechanics.

To address hallux valgus and other deformations, one must create an opposing force to prevent the development of an increase in this angle, such as creating a box that is completely rigid along the sagittal plane, side to side (see Figure 8). In conventional pointe shoes, boxes are not rigid but, rather, "squishy" along the sagittal plane. The proposed pointe shoe design involves selecting supportive, nondegenerative materials to ensure rigidity of the box's sagittal plane. Unlike the natural materials currently used in pointe shoes, the proposed materials would remain supportive throughout the life of the shoe. This increased lifespan would be another significant innovation. All the ballerinas we interviewed expressed regret that their pointe shoes "die" (degenerate) quickly (from a few classes to up to two months, depending on the amount of time a dancer spends *en pointe*).

The goal of using innovative materials is to create pointe shoes that remain comfortable for an increased time. Perhaps initially more expensive, the innovative pointe shoe would save ballerinas money in the long run. A professional ballerina can go through up to three pairs of shoes in one performance – roughly three hours of dancing (Kippen, 2004).

Another issue ballerinas face is the loudness of the sound that results when the box strikes the floor. Placing a thin layer of sound- and shock-absorbent foam or elastomeric material between the box structure and cover can alleviate this problem.

The shank. The shank is the supportive sole of a pointe shoe and enables a dancer to balance on the tips of her toes. When the dancer is on pointe, her weight is on the platform, but in order for her to rise up on toe-point in a controlled way and stay there, her foot needs something against which

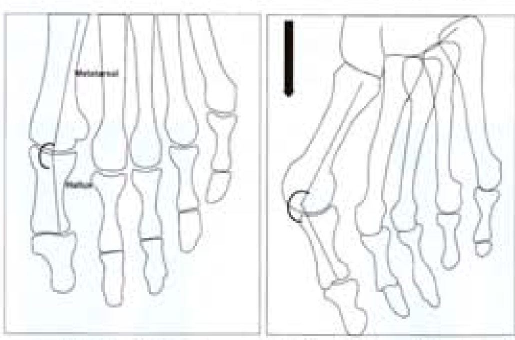

Figure 7. Because of pressure from the dancer's body weight, the angle between the metatarsal and hallux will tend to increase (a deformity known as hallux valgus, *or bunions).*

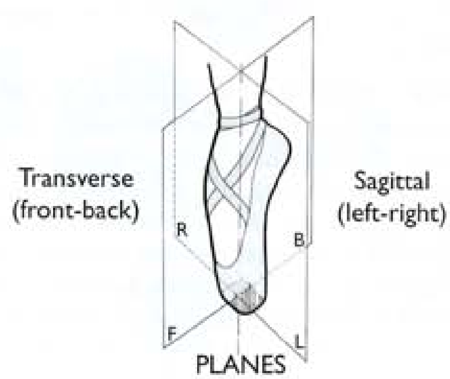

Figure 8. Diagram illustrating sagittal and tranverse planes of a foot en pointe.

Figure 9. During interview, ballerina points to specific area of shoe that does not respond to her movements.

Figure 11. Ballerina's shoe separates from the rest of her foot when she rises and lowers from relevé.

to press for support. The shank, resting along the bottom of her foot and particularly under her arch, provides that rigid surface. It is one of the most difficult parts of the shoe to design because it must have opposing properties. Similar to the box, the shank must be completely rigid along the sagittal plane. Along the transverse plane, however, it must have controlled flexibility. This is intrinsically related to the human anatomy (see Figure 3, page 8): In the human foot, muscles run up and down the bones, but there are no muscles that run laterally.

The shoe must provide complete support in the sagittal plane; if any movement is permitted in this direction, there are no muscles to bring the foot back to a stable position, and injuries may result. Along the transverse plane, however, because there are muscles running up and down the foot, the dancer can rise from the flat to the fully pointed position. The design of the pointe shoe must have controlled flexibility to allow this smooth transition to occur. Conventional shanks have a uniform thickness, but the foot does not need the same support everywhere. In personal interviews, all ballerinas complained that the shoe did not bend as they desired under the metatarsal area (Figure 9), and in fact, this area needs the least amount of support (see Figure 10).

Based on our interviews and observations, we discovered that the only area of the shank needing complete support is the area under the toes. The rest of the shank's support must

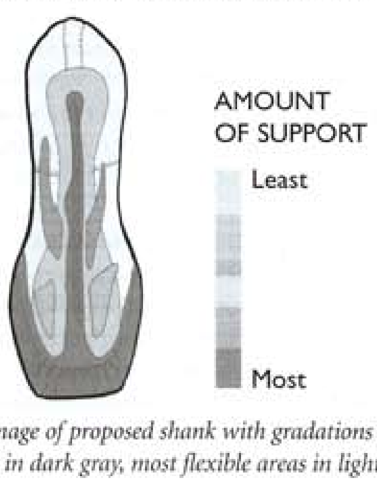

Figure 10. Image of proposed shank with gradations in stiffness. Stiffest areas in dark gray, most flexible areas in light gray.

gradate from there. Another proposed innovation is making the shank and box one piece. In conventional pointe shoes, the box and shank are separate pieces, but combining them continues the areas of support across the sides and promotes a stabilized fit. We constructed several models of the box-shank combination. While mixing polyester resin for the shanks, we noticed that the plastic wedges used for mold release had better elasticity than the carbon fiber shanks. This serendipitous event encouraged us to think of different materials, among them polyurethane, tempered steel, titanium, and carbon fiber.

The quarter. The quarter covers the heel and sides of the foot. In conventional shoes, it utilizes ribbons, elastics, and drawstrings to keep the shoe snug against the dancer's foot (Seibel, 2005). These parts rarely do their job. As seen in Figure 11, ribbons do not keep the shoe properly on the foot, and especially when going through the demi-pointe position, the shoe separates from the foot.

Ballerinas have a habit of tying their ribbons too tightly. As shown in Figure 12, the skin is squeezed around the ribbons because of the tightness. Prolonged use of tight ribbons results in lifelong problems such as Achilles tendinitis (Spilken, 1990).

In the new design, a single elastic quarter is proposed. This quarter covers the entire foot and rises up slightly higher than the conventional quarter to form a boot. This design molds to any foot and keeps the shank tight against the foot. Almost all ballerinas, in both questionnaires and interviews, expressed a preference that ribbons be presewn and that pointe shoes have a "use-off-the-shelf" quality. The elastic quarter eliminates any need of sewing and provides a better fit than ribbons or elastics.

Figure 12. Dancer's ribbons are tied too tightly.

TABLE 3. RESULTS OF USER FEEDBACK

Number of Dancers Who Rated Feature Highly	Platform Inclination	Boot Shoe	Memory-Foam Lining	Shank-Box Combination
Discussion group (n = 10)	9	10	10	7
Tried on shoe (n = 2)	N/A	2	2	N/A

The Prototype Pointe Shoe

A prototype incorporating the redesigned elastic was tested informally with 12 ballerinas and received strong support (see Figure 13). All respondents expressed enthusiasm for our design improvement ideas, especially the boot shoe and the memory foam lining (see Table 3). Suggestions such as putting ribbons on the boot shoe in order to preserve the classical look were made by a couple of ballerinas as they became interested in the possibility of wearing the innovative shoe during a performance. Two of the dancers tried the prototypes, and, concurrent with the results of the discussion, expressed strong support for the prototyped boot shoe and memory foam lining.

Conclusion

Through observational research with professional and preprofessional ballerinas, we were able to identify the critical needs that have not previously been met by traditional pointe shoes. These needs were used as a starting point for a design exploration to develop a shoe that would revolutionize the staid world of ballet shoes.

The proposed design shows great potential for meeting the project goals. Preliminary evaluations with ballerinas indicated that the memory foam lining and the elastic quarter – two features that were represented in the prototypes – were immediately accepted. The integral box-and-shank design could not be objectively evaluated because of prototype shortcomings, although this feature was deemed to be worthy of further refinement.

Future steps for this project involve developing a higher-fidelity prototype that can be used to conduct more extensive testing and evaluation. This user research will help us determine the functionality and effectiveness of the new design and provide feedback for further iterations. We hope eventually to explore the possibility of patenting and developing the design for manufacture.

Figure 13. Prototype of boot shoe.

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Lina A. Colucci conducted this research for her 10th-grade science fair project at Lexington High School, Lexington, MA. The work won first place at the Massachusetts State Science Fair. Colucci was selected as a member of the Massachusetts delegation to the American Junior Association of Science (the junior division of AAAS) convention. This project also went on to place first in the poster division of the Junior Science and Humanities Symposium.

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