

Research Article

Acute Effect of Toe Cap Choice on Toe Deviation Angle and Perceived Pain in Female Professional Ballet Dancers

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Received 7 January 2019; Revised 16 February 2019; Accepted 19 March 2019; Published 10 April 2019

Academic Editor: Ayhan Cömert

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Several classical dance complex movements, such as *pointe*, require body weight to be supported properly to avoid risk of foot injury. Regarding the choice of toe cap for *pointe* shoes, it is unclear which type can better alleviate pain symptoms and toe deviation angle in dancers. The aim of the current crossover study was to investigate the acute effect of using different types of toe caps among well-trained professional dancers on pain perception and toe deviation angle. Ten young female professional dancers volunteered to participate in the study. Each participant was tested during two separate sessions with an interval of 72 h in between. Participants were tested in the two sessions with a standard commercial or a customized prototype toe cap, always with *pointe* shoes, and in randomized order. An anteroposterior X-ray examination was performed separately for each participant and a visual analogue scale for pain perception was administered following each situation (with a standard commercial or a customized prototype toe cap). Significant amelioration was obtained when a customized toe cap prototype was used both for toe deviation angle and for visual analogue scale. Use of a customized toe cap prototype compared to a standard one may acutely reduce both toe deviation angle and pain in elite female professional dancers.

1. Introduction

The foot is able to provide the greatest amount of proprioceptive information (PI [1, 2]) and the central processing of this information is considered essential for balance control [3]. For example, knowing how high to jump over an obstacle so as not to strike it with the foot requires high kinaesthetic awareness. As a platform of stability, PI on the foot comes from receptors in the heel front, under the metatarsals' heads, under the big toe, and in the foot's lumbrical muscles [4, 5]. Some authors even claim that some PI comes from the lower

limb muscles as well [6]. The plantar aspect of the foot analyses variations in support on the ground and provides all feedback and feedforward information needed for orthostatic equilibrium management [5, 7]. Feedforward involving activation of leg and trunk muscles and feedback involving sensory signals together regulate the maintenance of vertical posture [8–12]. There is a continuous drift of information regarding *status* and function of the musculoskeletal system from PI to the spinal cord, *cerebellum*, and brain; and, when there is a failure in communication process or when one or more sensors send inadequate information, movement

efficacy is reduced. As such, standing and moving on a wobbly surface induces body horizontal instability [7].

Alterations in stability or postural control associated with differences in supporting surfaces could influence the responses of available somatosensory information, resulting in increased neuromuscular flow, fatigue, and pain [7, 13]. For example, when standing on one leg or moving on a confined surface, as is the case for dancers (i.e., ballet dancers), this could affect overall postural control [14–16].

Dancers place high demands on the foot and ankle. A dancer's foot is a strong but sensitive, stable, elastic, and specific structure, which supports changes of direction [17]. Several complex movements requiring high-level motor skills and good postural control have been investigated in many studies [18, 19]. Among these actions, dancers are asked to move from bipedal to monopodal support while keeping whole body stability, to jump and turn at the same time, or to perform *passé en demi-pointe* positions. These highly accurate actions in classical ballet require the accurate interpretation of vision and especially of PI coming from the feet [19]. In more complex movements, such as *pointe* exercises, ballerinas have to support their body weight on the tips of fully extended feet within *pointe* shoes sometimes with foot-protecting caps. To perform *pointe* exercises well, it may be useful to make use of targeted exercises, such as *relevés*, which strengthen and give stability to the ankle. This often entails placing a well-trained ballet dancer's body in positions that require high flexibility and controlled power, but even this can put excessive stress on the foot, contributing to the presentation of bunions or metatarsal fractures [20–26].

In *relevé*, simultaneous pain is usually generated or increased with active ankle or foot plantarflexion. During *relevé*, there is extension of a chain of joints starting from the *tibiotalar* one in order to reach the interphalangeal joints. When standing *en pointe*, plantarflexion of the foot and ankle forms a minimum 90° angle [27]. More precisely, during the rise on the tip, the *talus* rotates and slides inside the mortise until it stops, while the *talus-scaphoid*, the *scaphoid-cuneiform-cuboid* (between the metatarsal and *tarsus* bones), and the metatarsal-phalanges provide instep support. The ankle and hindfoot, with help from minor joints, allow for alignment between the knee, the *malleolus*, and toes. Body weight is thus equally distributed and the lower limb's *aplomb* is guaranteed. Muscles responsible for maintaining the tip are toe, *hallux* flexors, and *peronei*. They accomplish the tasks of extending the ankle and joints below it, stabilizing the ankle, and pushing the *talus* forward using the *malleolus* as a *fulcrum*. On the other hand, if this stability is lost due to defects in joint extensions, the dancer will be more prone to injuries, including capsular, ligament, and bone injuries [23].

Pointe movement is performed using *pointe* shoes, which help to strengthen the toe/ankle structure and distribute the dancer's weight throughout the foot. *Pointe* shoes help in sufficiently decreasing the load on toes to enable a ballerina to sustain her body weight during vertical positions. However, training with *pointe* shoes has been demonstrated to increase peak pressure on the foot compared with being barefoot (41 vs. 86 N/cm² [28]). In addition, moving to a vertical

position from a footed one has been shown to increase peak pressure up to 115 N/cm² [29]. A dancer's body is sustained by the toes' tips [30], which can augment pressure on the first toe, forcing it into valgus, thereby possibly contributing to *hallux valgus* deformity [31]. However, it remains unclear whether or not toe cap choice is associated with the greater formation of *hallux valgus* in well-trained dancers. Given the above challenges, together with rigorous performance expectations, investigating and preventing injuries in well-trained ballerinas can be difficult. The aim of the current study was to investigate the effect of using a new CTC (vs. an STC) among well-trained professional dancers on pain perception and toe deviation angle (TDA). We hypothesized that both (1) TDA and (2) pain perception were acutely lower with a CTC prototype compared with an STC.

2. Materials and Methods

2.1. Protocol. The overall design of our study was a crossover study design. Before experimentation started, all participants or, in the case of minors, their parents reviewed and signed consent forms specifically approved by the local ethics committee guidelines. The local ethics committee (Scientific Committee of Posturology Center) approved the entire study design, which was conducted according to the ethical standards of the 1964 Helsinki Declaration.

2.2. Subjects. For the sample size calculation, a pilot study that included a sample of 8 participants was performed *a priori* and gave a statistical power greater than 0.81. Therefore, ten young female professional dancers (age: 18.6±3.8 [mean±SD] yrs, body mass: 55.8±6.3 kg, height: 162.9±4.4 cm, training experience 14.4±2.9 yrs, weekly training 10.3±3.9 h) volunteered to participate in this study (Table 1). Participants completed medical history and dietary questionnaires. The inclusion *criteria* were as follows: onset of *hallux valgus* (diagnosed by an orthopedist) and/or sprained first metatarsophalangeal (MTP) joint medial collateral ligaments (sonogram or MRI-verified), being a classical modern female dancer, having training experience in ballet of ≥10 yrs, having an average training frequency of ≥5 h per week, not having been given any chronic medication that could affect inflammation responses or bone development, not being involved in the practice of any structured physical exercise other than ballet or training for it, and not being treated for any muscle or joint injury.

2.3. Procedures. Each participant was tested during two separate sessions with an interval of 72 h in between. Participants (both of their feet) were tested in the two sessions, once with an STC and once with a CTC, always with *pointe* shoes, and in randomized order (Figure 1). Participants did not know which toe cap condition they were currently being tested in, because they put their shoes on helped by an operator with this operation hidden by a screen.

Participants were also asked to avoid smoking and consuming caffeinated drinks in the 24 h before testing. All procedures were performed at the same daytime period to avoid any circadian effects and at a controlled temperature

TABLE 1: Participants' data.

ID	Body mass (kg)	Height (cm)	Age (y)	Training experience in dance (yrs)	Average training frequency (hrs/week)	Dominant foot
Subject 01	50.7	160	15	12	6	Left
Subject 02	62.7	163	17	14	20	Right
Subject 03	61.5	164	25	20	6	Right
Subject 04	49.0	158	22	17	10	Right
Subject 05	67.1	170	19	15	10.5	Right
Subject 06	54.6	160	21	15	10.5	Right
Subject 07	57.8	165	22	16	10.5	Right
Subject 08	52.8	156	16	12	12	Right
Subject 09	54.1	168	16	13	10	Right
Subject 10	47.7	165	13	10	8	Right
Mean	55.8	162.9	18.6	14.4	10.3	
SD	6.3	4.4	3.8	2.9	3.9	
Range	47.7	156	13	10	6	
Min						
Max						
Inclusion criteria	Onset of <i>hallux valgus</i> , classical modern female dancer, training experience in ballet ≥ 10 years, average training frequency ≥ 5 hrs/week					
Exclusion criteria	Injury (other than <i>hallux valgus</i>)					

Note
SD=Standard deviation.

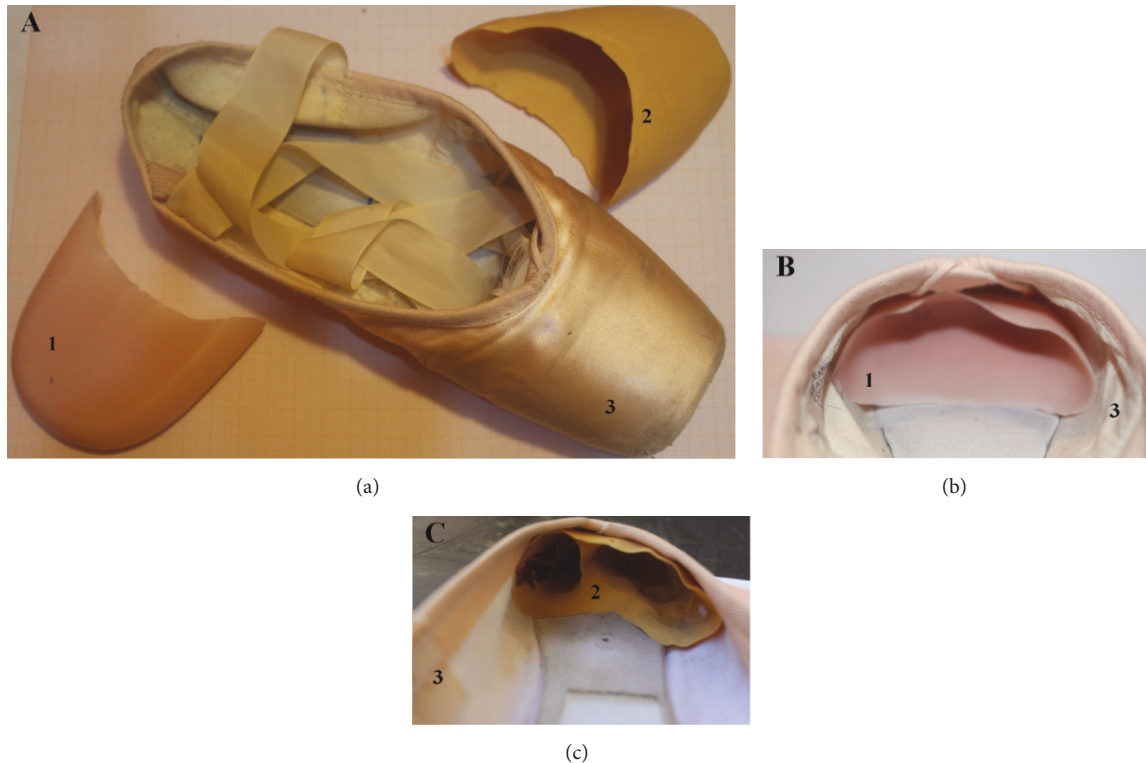


FIGURE 1: Toe caps: standard commercial toe cap (a), customized toe cap prototype (b), and *pointe* shoe (c).

of 24°C. Participants were requested to refrain from training in the 24 h before testing and to maintain their usual diet. The same investigator always took anthropometric measurements on the morning of the first testing day. Measurements of body mass (kg) and height (cm) were taken for all participants. Body mass was measured to the nearest 0.1 kg, with the subject in light clothing and without shoes, using an electric scale (Model Tanita BC-418, Tokyo, Japan). Each patient also underwent an anteroposterior X-ray examination.

Each participant was asked to perform the classical dancer's standard en pointe position for the purposes of radiographic assessment. An X-ray examination was always performed by the same radiologist with 32 years of experience with a FDR D-EVO (Fujifilm, Japan). The position duration was 10 s for both the STC and the CTC. An example is shown in Figure 2. After each position, a VAS for pain perception (a horizontal line, 100 mm long, and with word descriptors at each end) [32] was administered to each participant. Each X-ray was analyzed by the same radiologist with DICOMDIR software (<https://www.radiantviewer.com/it>) to assess TDA (°), i.e., between the *phalanx* and first metatarsal.

For this investigation, we used silicone gel STCs (Techdance, San Giovanni Teatino, Italy) and custom-built CTCs (E!n Pointe, Salerno, Italy) inside *pointe* shoes (Fouette, Grishko, New York, USA). The STCs were generally rubber (easily deformable) caps. Each CTC (35-shore rigidity) was specifically shaped for each specific dancer's foot by using a handmade biocompatible silicone mix (catalyst+silicon base ratio=1:1). After the silicone mix solidified (catalyzed) around the dancer's foot, the CTC was further milled and its silicon

mix excess removed before it was ready for use. The whole manufacturing process took about 30 s [33].

2.4. Statistical Analysis. The paired Student's *t*-test was used to investigate whether significant differences existed between the two different conditions (CTC vs. STC) in terms of TDA and the VAS. The Shapiro-Francia test was firstly used to assess normal data distribution. Effect size was calculated as Cohen's *d*. For its interpretation, the following thresholds were used: small=0.20, medium=0.50, and large=0.80. The accepted significance level was set at $P < 0.05$. The analysis was performed with MedCalc Statistical Software version 18.2.1 (MedCalc, Ostend, Belgium).

3. Results

The Shapiro-Francia test showed a normal distribution of data with $W^2=0.971$ and $P=0.891$ for TDA and $W^2=0.999$ and $P \approx 1.000$ for the VAS, respectively. The paired Student's *t*-test showed that both variables significantly differed between the two conditions. In particular, significant amelioration was obtained when a CTC was used for both TDA, with an average 5.9° reduction ($t_{(1,9)}=-5.854$; $P=0.0002$; $d=1.89$, large), and VAS, with an average 3.1 reduction ($t_{(1,9)}=-11.196$; $P=0.00005$; $d=3.66$, large). Raw data and analysis outputs are presented in Table 2 and Figure 3, respectively.

4. Discussion

The first finding of the current study was that TDA was significantly higher with an STC compared with a CTC

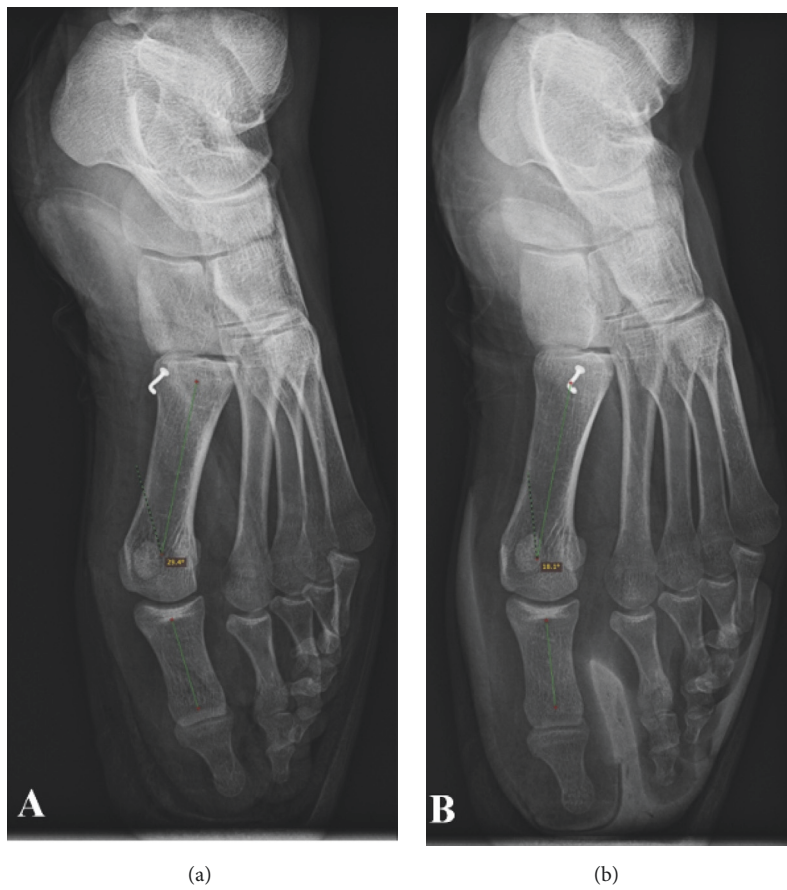


FIGURE 2: X-ray example: toe deviation angle with standard toe cap (a) and with customized toe cap (b).

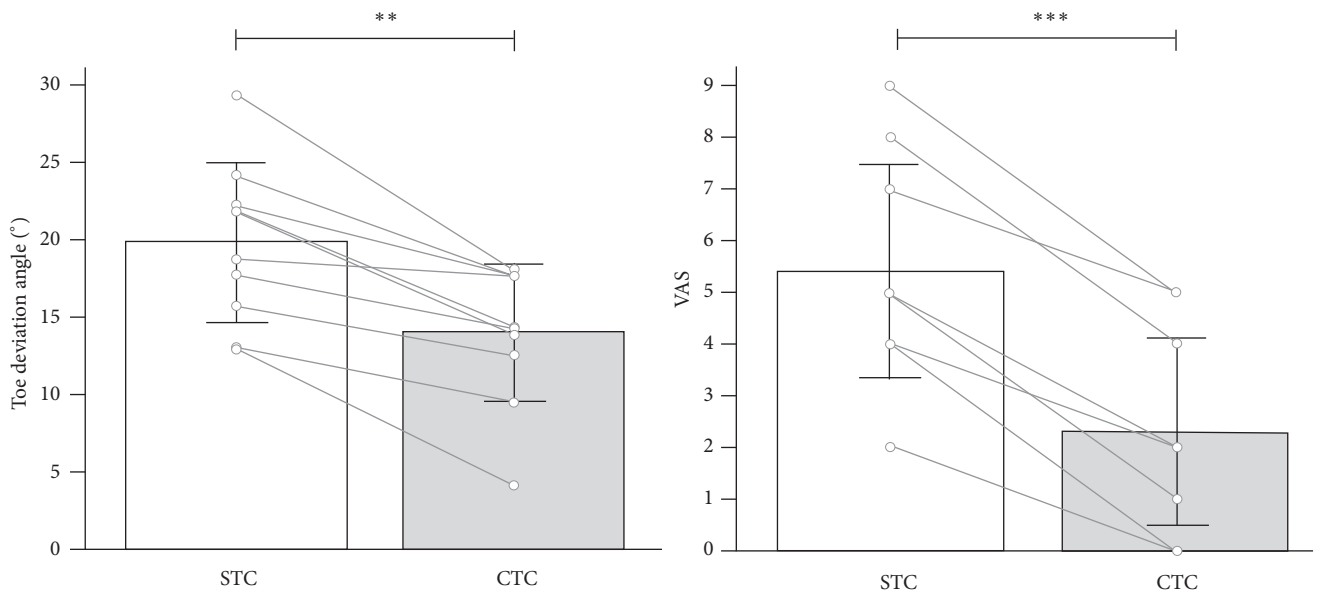


FIGURE 3: Toe deviation angle with standard toe cap and with customized toe cap for all participants. ** $P=0.0002$, *** $P=0.00005$.

TABLE 2: Toe deviation angle and visual analogue scale of each participant.

ID	TDA with STC (°)	TDA with CTC (°)	TDA difference (°)	VAS when dancers are on toes with STC	VAS when dancers are on toes with CTC	VAS difference
Subject 01	29.4	18.1	-11.3	8	4	-4
Subject 02	22.3	17.7	-5.6	5	2	-3
Subject 03	18.8	17.7	-1.1	9	5	-4
Subject 04	24.2	17.7	-6.5	7	5	-2
Subject 05	21.9	13.9	-8.0	4	2	-2
Subject 06	21.9	14.4	-7.5	2	0	-2
Subject 07	17.8	14.3	-3.5	5	2	-3
Subject 08	15.8	12.6	-3.2	5	1	-4
Subject 09	13.1	9.6	-3.5	4	0	-4
Subject 10	13.0	4.2	-8.8	5	2	-3
Mean	19.8	14.0	-5.9	5.4	2.3	-3.1
SD	5.1	4.4	3.1	2.1	1.8	0.9
Range	13.0	4.2	-1.1	2	0	-2
P value	29.4	18.1	-11.3	9	5	-4

VAS with STC vs. VAS with CTC P=0.00005

Note

TDA=toe deviation angle; STC=standard toe cap; CTC=customized toe cap; VAS=visual analogue scale; SD=standard deviation.

prototype. The second finding was that the VAS value for pain perception was significantly higher (i.e., worse) when dancers had shoes with an STC ($P=0.00005$). Any toe cap is strongly embedded inside the *pointe* shoe and tightly encases the toes, so that the ballerina can stand on an oval-shaped support when in the *en pointe* position (Figure 1). A toe cap may be more or less rigid/flexible depending on the model. Traditional models are thin and barely protect the toes' head while providing more support along the foot's sides. According to Teiz et al. [34], force variation in the foot and toe is more dependent on toe length, foot position, and padding or cap use. Force induced on the second toe, the longest one, depends on the toe cap structure and length [34]. According to these authors, during *pointe* or *relevé*, this force increases on the MTP joint. With a toe cap, the distance between the first and second toe reduces allowing for an MTP joint angle deviation reduction (Figure 2).

On the other hand, many studies have investigated different injuries with specific incidences ranging from 27% to 49% in ballet, modern, flamenco, and tap dancers [35–37], with female ballet dancers experiencing the highest incidences. During certain complex movements, such as *pointe*, *relevé*, or *pirouette*, a high force is generated on the dancer's ankle-foot area. During "softer" activities, such a force can reach up to five times the body weight while walking and ~13 times the body weight while running [38]. Considering the great forces developed against the foot and its shape, it is not surprising that toes are the most frequently injured body part and thus the foot represents the main pain site in dance. CTC efficacy in preventing pain is well demonstrated by the current study. This toe cap includes pouches encapsulating the toes inside the unyielding shoe, both cushioning them against shocks to the foot and reducing friction, which potentially causes blistering.

Our study has some limitations. Firstly, it was only focused on the effects resulting from the acute use of customized toe pads exclusively by standard classical dancers in the standing *en pointe* position. It remains unknown what the chronic clinical benefits of the customized toe pads are. Furthermore, sample size was small.

5. Conclusions

Toe caps are designed to protect toes and provide grip and stability during complex movements, such as dancing *en pointe*. Whereas some ballerinas still prefer not to use any type of toe cap or pad inside their shoes, others, especially well-trained dancers, are nowadays increasingly more interested in different caps, cushions, and wraps types. In the current study, well-trained professional ballerinas experienced less foot flexibility and deviation angle in addition to less pain perception (almost half) while exercising with a CTC prototype compared with an STC. The effect in terms of injury prevention of CTC use, both chronically and/or during further specific dance movements, is worthy of future investigations.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

Annamaria Salzano and Fabiana Camuso share first authorship, and Luca Paolo Ardigò and Johnny Padulo share last authorship for this study. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

Conflicts of Interest

The authors do not have any conflict of interest in this paper. Annamaria Salzano and Fabiana Camuso provided the customized toe cap prototype used for present study (patent 202018000000534).

Acknowledgments

The authors would like to thank all involved experts, coaches, and medical teams for their collaboration. In addition, they are grateful to the study participants and their parents for their cooperation.

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