The effect of toe padding on dancing ballet en pointe

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Abstract

The objective of the study was to compare normal forefoot pressure of female ballet dancers during rises en pointe in gel toe pads, custom molded toe pads, and the participant's usual padding, to understand how toe padding may impact dancer's foot health. The use of pointe shoes often causes concentrated areas of high pressure on the forefoot due to their tight fit and the large load they require the forefoot to bear. These pressure points can lead to overuse injuries and painful surface ailments. Decreasing these areas of concentrated high pressure may be achieved with the use of toe padding. Normal contact pressure on the forefoot was recorded as thirty female ballet dancers performed rises en pointe, balances in retire, and échappés to second at the barre. They completed these ballet steps in each of the padding conditions (gel toe pads, custom molded toe pads, usual padding) with six piezoresistive pressure sensors fixed to anatomical landmarks on their forefeet. The pressure data was filtered and normalized to participant's bodyweight. To compare entire waveforms instead of discrete values, a principal component analysis was used, and principal component scores (*PC-scores*) were calculated for the pressure waveforms. A repeated measures ANOVA was used to compare the *PC-scores* across conditions.

The results of the ANOVA indicated that there was a significant difference between the gel toe pad and the other conditions at the medial and dorsal sides of the first MTP joint during all the ballet steps ($p<0.047$ for all). The gel toe pad had higher *PC-scores* therefore this toe pad had higher overall pressure magnitudes compared to the other toe pad conditions. There were significant differences between the custom molded toe pad and the other padding conditions at the fifth MTP joint during rises ($p<0.001$) and balances in retire ($p<0.001$), and the first PIP joint during rises ($p=0.008$). During échappés, there were differences between the gel and custom toe pad conditions at the first PIP joint ($p=0.047$) and at the fifth MTP joint ($p<0.001$). The custom molded toe pad had lower *PC-scores* than the other conditions indicating these pressure waves had smaller overall magnitudes. Results indicate the use of custom molded toe pads can decrease normal contact pressure on the fifth MTP joint and the first PIP joint compared with other types of toe pads. Results also show that at the first MTP joint, gel toe pads can increase the normal contact pressure compared with other types of toe pads. Dancers may consider the use of carefully planned fit accessories, or custom molded toe pads, to aid in the relief of concentrated areas of high pressure on their forefeet.

Abrégé

L'objectif de l'étude était de comparer la pression normale sur l'avant-pied de danseuses de ballet lors de montées sur pointes avec des embouts en gel, des embouts moulés sur mesure et le rembourrage habituel de la participante, afin de comprendre comment le rembourrage des orteils peut avoir un impact sur la santé des pieds de la danseuse. L'utilisation de pointes provoque souvent des zones concentrées de pression élevée sur l'avant-pied en raison de leur ajustement serré et de la charge importante qu'elles imposent à l'avant-pied. Ces points de pression peuvent entraîner des blessures de surmenage et des affections superficielles douloureuses. Il est possible de réduire ces zones de pression élevée concentrée en utilisant un rembourrage des orteils. La pression de contact normale sur l'avant-pied a été enregistrée pendant que trente danseuses de ballet exécutaient des levées sur pointes, des équilibres en retraite et des échappés à la barre. Elles ont effectué ces pas de ballet dans chacune des conditions de rembourrage (embouts en gel, embouts moulés sur mesure, rembourrage habituel) avec six capteurs de pression piézorésistifs fixés à des points de repère anatomiques sur leurs avant-pieds. Les données de pression ont été filtrées et normalisées en fonction du poids corporel du participant. Pour comparer des formes d'ondes entières plutôt que des valeurs discrètes, une analyse en composantes principales a été utilisée et des scores en composantes principales (scores PC) ont été calculés pour les formes d'ondes de pression. Une ANOVA à mesures répétées a été utilisée pour comparer les scores de composantes principales entre les conditions.

Les résultats de l'ANOVA ont indiqué qu'il y avait une différence significative entre le coussinet en gel et les autres conditions sur les côtés médial et dorsal de la première articulation MTP pendant tous les pas de ballet ($p<0{,}047$ pour tous). Le coussinet en gel a obtenu des scores PC plus élevés, ce qui signifie que ce coussinet a exercé des pressions globales plus importantes que les autres coussins. Il y avait des différences significatives entre le coussinet moulé sur mesure et les autres conditions de rembourrage au niveau de la cinquième articulation MTP pendant les montées ($p<0{,}001$) et les équilibres en retraite ($p<0{,}001$), et au niveau de la première articulation PIP pendant les montées ($p=0{,}008$). Pendant les échappés, il y a eu des différences entre le gel et les embouts moulés sur mesure au niveau de la première articulation PIP ($p=0{,}047$) et de la cinquième articulation MTP ($p<0{,}001$). Le coussinet d'orteil moulé sur mesure présentait des scores PC inférieurs à ceux des autres conditions, ce qui indique que ces ondes de pression avaient des amplitudes globales plus faibles. Les résultats indiquent que l'utilisation d'embouts moulés sur

mesure peut réduire la pression de contact normale sur la cinquième articulation MTP et la première articulation PIP par rapport à d'autres types d'embouts. Les résultats montrent également qu'au niveau de la première articulation MTP, les embouts en gel peuvent augmenter la pression de contact normale par rapport aux autres types d'embouts. Les danseurs peuvent envisager l'utilisation d'accessoires d'ajustement soigneusement planifiés, ou d'embouts moulés sur mesure, pour aider à soulager les zones concentrées de pression élevée sur leurs avant-pieds.

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Contributions of Authors

Kristin Higgins, MSc Candidate, Department of Kinesiology and Physical Education, McGill University, was responsible for the research design, data collection, data processing, data analysis, statistical analysis, and composition of this thesis. The candidate's supervisor Dr. Shawn Robbins, Associate Professor, School of Physical and Occupational and Therapy, McGill University, is responsible for research design, data analysis, support throughout thesis writing, and manuscript revisions. The candidate's committee members, Dr. David Pearsall, Associate Professor (retired), Department of Kinesiology and Physical Education, McGill University, and Dr, Celena Scheede-Bergdahl, Senior Faculty Lecturer and Undergraduate Program Director, Department of Kinesiology and Physical Education, McGill University are responsible for research design and support throughout the project.

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1 Background

In the past decade, the Canadian Council for the Arts and the Ontario Arts Council have published several studies exploring dance in Canada and its impact on Canadians. Today there are over 400 dance schools offering ballet training, that are registered with the Canadian Council for the Arts across Canada (*Summary of the Dance Mapping Study*, 2016). Within Canadian dance programs targeted at child and youth development, there was a median of 200 participants in each program (Ekos Research Associates, 2016). These dance programs have encouraged Canadians to make connections with others in their community and allowed people to participate in a form of exercise they enjoy; as respondents cited their top three reasons for participating in dance as overall enjoyment, exercise and fitness, and social connection (Ekos Research Associates, 2014). Dance has become a popular pastime for children and youth, with a growing number of adults participating as well. Additionally, there are now over 40 ballet companies across Canada, sharing the art for audiences to enjoy, and growing the Canadian culture (*Summary of the Dance Mapping Study,* 2016).

Due to the popularity of ballet across Canada and the world, many dancers are working towards building the strength, flexibility and technique required to dance en pointe. Pointe shoes are the ballet dancer's most important tool, they allow a dancer to rise onto the tips of their toes which gives dancers the illusion of weightlessness and elongated body lines. Since their first use in the early 1800s, they have become an icon of ballet. The pointe shoe is composed of a toe box, which provides the base of support, and a hard shank that runs along the sole of the shoe. The first iterations of pointe shoes were merely satin slippers with extensive darning at the toe tip, but are now usually made from layers of satin, leather, burlap, cardboard and glue as these allow the shoe to mold to the foot (Barringer & Schlesinger, 2021, p. 4).

Relatively few changes have been made to pointe shoes in the last 100 years compared to other types of athletic footwear. They are still mostly made from natural materials whereas other types of athletic footwear are now generally made from synthetic materials. Due to their composition being natural materials, they break down incredibly quickly. Perhaps one of the most staggering ballet statistics is the rate at which dancers go through pointe shoes. One of the most prestigious ballet companies in the world, the New York City Ballet, purchases about 8,500 pairs of pointe shoes each year, with each pair lasting an average of two days (Fierberg, 2020).

The shoes must be discarded because dancers are at a greater risk for injury when their shoes can no longer provide the required support to their feet and ankles (Ryman, 2015). The support a pointe shoe provides a dancer is imperative to dancer's health and safety.

To support the foot en pointe, pointe shoes impose a tight fit and high load on the forefoot which may be contributors to dancer's risk of musculoskeletal injuries and uncomfortable surface injuries. Injuries and other health issues are not uncommon in ballet. Among professional, female ballet dancers, there is an injury rate of 1.46 injuries per 1000 dance hours with 64% of those being overuse injuries (Harris, 2015). The way in which dancers address these injuries as well as pain, and hunger in general has been a topic of study due to the unique outlook and culture in ballet (Aalten, 2007). Classical ballet technique is learned by repetitive motions until the dancer can perform them precisely and accurately without thinking, which is theorized to contribute to an absence of body awareness for dancers and a separation between body and mind. Any injuries and pain they experience for their art can become seen as necessary and even admirable among professional dancers (Aalten, 2007). This can cause dancers to not properly rest and recover when they experience an injury. Injury can therefore hinder the development of professional dancers due to the continuing use of an injured body part, or, when they do sit out from an injury, missed training time. It also restricts recreational dancers from enjoying the art form as they may consider ballet and pointe work to be to uncomfortable or painful.

Pointe shoe related injury is a topic that has been studied, however, fit accessories are another factor pertaining to pointe shoe related injury and ballet dancer's foot health that is rarely considered. The use of toe padding and fit accessories may be an ideal way to aid in the relief of painful surface ailments as well as reduce the risk of overuse injuries. Currently, there is little research and understanding into what types of toe padding should be used, and how it should be placed in the shoe to achieve best results. By reducing the discomfort dancers feel en pointe, as well as reduce their risk for overuse injuries, more people can enjoy and advance the artform. The purpose of this study was to understand how gel toe pads, custom molded toe pads, and the participant's usual toe padding impacts the pressure distribution on the foot as well as dancer's perception of comfort, pressure, control, stability, articulation, and overall performance.

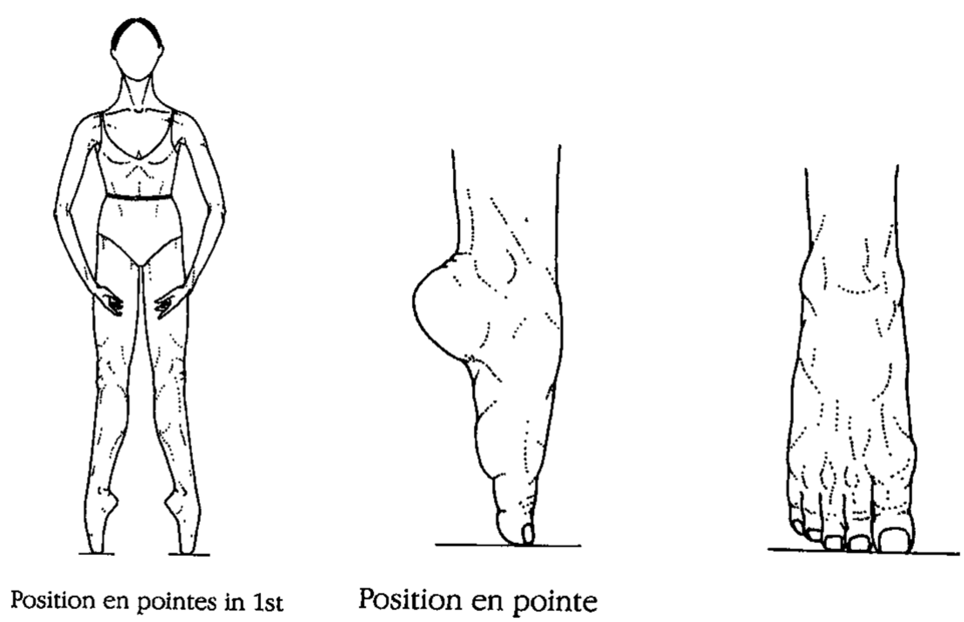
2 Literature Review

2.1 Kinematics and kinetics of rising to full pointe

The rise is a basic step in ballet that is often used in a barre warm up to prepare the body for larger motions. It is also used as a strength and conditioning exercise for the feet which builds dancer's pointe technique (Ryman, 2015). During the rise from flat foot to full pointe, the dancer begins from a flat foot stance, and lifts their heels, rolling through a stance on their metatarsals, called demi-pointe, until they stand on the tips of their toes in one fluid motion. Throughout this motion the dancer exercises as much external rotation from the hip, knee, and ankle as possible, known in ballet as "turn out." When balanced en pointe, the ankle and foot bear high loads at their extreme ranges of motion (Macintyre & Joy, 2000) and due to the small base of support on full pointe, the pelvis and spine position must be well controlled to maintain balance (Ryman, 2015, p. 101). The body and foot's placement on full pointe in first position are shown below in

Figure 2-1

The dancer's body and foot on full pointe (Ryman, 2015)



Note. Used with permission from the Royal Academy of Dance

When performing a rise, the dancer is often required to perform the action while keeping the rest of their body still, so there is little momentum to assist with the task. A study of two ballet dancers found that throughout a rise, the muscles crossing the ankle joints generated 67% of the total energy for one subject, and 78% of the total energy for the other subject. The muscles crossing the metatarsophalangeal joints (MTP joints) produced 33% and 22% of the generated energy for each subject respectively (Dozzi & Winter, 1993). This is a large energy contribution to the movement by the MTP joint's muscles when considering the cross-sectional area of these muscles is about one tenth of the cross sectional area of the muscles crossing the ankle joint. Proportionally, the muscles crossing the MTP joints may be exerting 2.5 to 3 times as much energy compared to the those crossing the ankle which may be a factor contributing to injuries around the MTP joints (Dozzi & Winter, 1993).

In order for the dancer to safely balance en pointe, their foot's axis should theoretically be parallel to their tibia, which requires a greater ankle range of motion than is found in the normal population (Macintyre & Joy, 2000). It was found that elite, professional, female ballet dancers did have increased plantarflexion compared to the normal population; however their dorsiflexion was less despite their total ankle flexion/extension range of motion remaining larger (Hamilton et al., 1992). Furthermore, study found that amongst experienced, female, ballet dancers, the ankle or tibia/talus bone pairing contributes about 72.3% of the total plantarflexion when standing en pointe, and the joints of the foot contribute the other 27.7% (Russell et al., 2011). If dancers do not have the required range of motion in the ankle and foot to safely balance on full pointe, dancers may be at a higher risk for injury (Macintyre & Joy, 2000).

Ballet dancers execute all of their movements with as much turn out (external rotation of the lower limbs) as possible; study has shown that 58% of the total external rotation of the lower limbs in ballet comes from above the knee, and 42% comes from below the knee (Hamilton et al., 1992). Elite, professional, female ballet dancers had an increase in their hip external rotation compared to the normal population, but a decrease in hip internal rotation. Similarly to the range of motion at the ankle joint, the total range of motion for the hip's internal and external rotation was still higher than the normal population (Hamilton et al., 1992). Dancers who do not naturally have a large hip external rotation may try and force the look of turnout by pushing against the floor (Macintyre & Joy, 2000) instead of gaining their body placement from their trunk and pelvis (Ryman, 2015). This can increase the dancer's risk of injury due to consequences of the forced stance such as increased valgus knee stress, increased tibial torsion, increased foot pronation, and increased Q angle (Macintyre & Joy, 2000).

To complete a rise to full pointe with good technique, strength, flexibility, and precision are required of the dancer. The pointe shoe is the dancer's most important tool outside of their own body and its performance is vital to dancer's overall health and safety en pointe.

2.2 Pointe shoe related injuries

Concentrated areas of high pressure on the foot are common in ballet and excessive force and pressure on the soft tissue and non-load bearing bones of the forefoot can cause dancers to experience issues such as bruised and thickened toenails, hammer toes, hallux rigidus, hallux valgus, Morton's neuroma, dorsal exostosis, sesamoiditis and extensor tendinitis (Barringer & Schlesinger, 2021, p. 371-383). Stress fractures to the bones of the feet are another common injury and dancers with Morton's toe are more likely to experience hammer toe and stress fractures to the second metatarsal bone (Barringer & Schlesinger, 2021, p. 377). Other injuries to the foot and ankle en pointe include Achilles tendinitis, plantar fasciitis, posterior impingement syndrome, and ankle sprains which are the most common injury to pointe dancers (Barringer & Schlesinger, 2021, p. 388-392).

Muscle strains in the foot are another common injury among pointe dancers, especially on the ball of the foot. This is due to the constant maneuvering of the foot from the demi-pointe position to the full pointe position (Dozzi & Winter, 1993). The flexor hallucis longus which spans from the calf to the hallux, crosses the metatarsophalangeal joint and plays a large role in this rising motion. This muscle in particular can experience strains and spasms due to overuse in ballet dancers (Fond, 1983).

Later in life, it is known that dancers experience arthritis in their lower extremities in greater numbers than non-dancers (van Dijk et al., 1995). Former professional female dancers between the ages of 50 and 70 had higher rates of arthrosis in the ankle, subtalar, and first metatarsophalangeal joint than the normal population. Professional ballet dancers who are currently employed have also been studied and 9 of the 15 dancers examined showed signs of osteoarthritis in 5 of the 6 joints examined (Angioi et al., 2014). Arthritis in the retired population was determined to be due to the repetitive micro-trauma at these joints from their ballet training (van Dijk et al., 1995).

Some dancers may be prone to these injuries due to their anatomy; however, all these injuries can be caused in part by factors relating to pointe shoes. Pointe shoes can cause concentrated areas of high pressure, provide insufficient shock absorption, and if fit incorrectly, can guide the foot into poor alignment. These injuries can all make dancing en pointe uncomfortable or painful which leads to lost training time for serious dancers, may prohibit recreational dancers from enjoying the art form, and may cause further complications during ageing.

2.3 Pressure inside the pointe shoe

Concentrated areas of high normal contact pressure can occur on the forefoot due to the tight fit of the shoe and the high loads that the forefoot is required to bear. Pressure is a function of force and contact area; pressure increases when the contact surface area decreases. Therefore, if a shoe is well fit, there will be good foot and shoe contact, and concentrated areas of high pressure will be decreased.

Using pressure sensitive film on the feet, the relative pressure distribution on the foot in pointe shoes has been found to be non-uniform (Torba & Rice, 1993). At least 35 force/pressure sensors were placed at locations across the forefoot and the normal contact pressure while standing en pointe was recorded while force plates recorded the ground reaction force for one experienced female ballet dancer. It was found that pressure was mostly concentrated at the joints with relatively low pressure between joints. Additionally, 85% of the ground reaction force was accounted for by the individual pressure sensors. This indicates that at least 85% of the ground reaction force while standing en pointe is transferred to the foot by normal contact pressure (Torba & Rice, 1993).

In a normal flat foot stance, the plantar pressure at the hindfoot is almost one third of the total recorded plantar pressure across all regions of the foot (Ang et al., 2018). In pointe shoes, the distribution has been found to be very different, the pressure at the heel and along the arch were found to be less than 25 kPa (Torba & Rice, 1993) compared to the pressure recorded on the forefoot reaching values higher than 920 kPa (Teitz et al., 1985).

Certain areas of the forefoot naturally have ample contact with the shoe, such as the distal end of the hallux. When en pointe, the distal end of the hallux can experience pressures over 920 kPa, with some measurements being off the scale of 1000 kPa. Dancers whose second toes are shorter than their first, experience higher pressures on the hallux than those with second toes of the same length or longer with no fit accessories (Teitz et al., 1985). Dancers with second toes that are the same length or longer than the hallux probably have more contact surface area on the distal end of their toes than those with a shorter second toe. This allows the pressure to be spread across more surface area and the pressure on the hallux is therefore decreased (Teitz et al., 1985). When dancers added padding to the distal end of their short second toes, the pressure ratio between the first two toes (2^{nd} toe/hallux) increased from 0.14 average to 0.33 average (Teitz et al., 1985). This further illustrates the relationship between pressure, normal contact force, and contact area.

Presently, it is understood that reducing areas of high pressure on the forefoot in pointe shoes may by achieved in part by increasing the contact surface area between the foot and shoe, however, it is difficult for manufacturers to improve fit and increase this contact area in stock shoes, due to the unique profile of each dancer's foot.

2.4 Joint alignment inside the pointe shoe

The exact placement of the forefoot inside pointe shoes is unique for every dancer, even the right and left can be different within one dancer. The first three toes lay and cross in different ways, and no correlation between toe position within the pointe shoe and other factors such as toe length and shoe style has been identified (Tuckman et al., 1991). In a study of the foot's position inside pointe shoes, molds of the feet were made for each foot of nine dancers, resulting in eighteen molds total. All eighteen molds showed hallux valgus when in the en pointe position, but only two of the participants experienced hallux valgus in normal flat foot stance (Tuckman et al., 1991). This suggests that the first ray's joint alignment is impacted by the pointe shoe.

Toe shape plays a role in the fit of pointe shoes but it has not been found to impact a dancer's ability to function en pointe (Ogilvie-Harris et al., 1995). It was found that dancers who have a second toe shorter than the first had less calluses on their feet and the lowest pain scores compared to dancers with other toe shapes, despite this toe shape experiencing the highest pressure at the distal end of the hallux with no toe padding (Ogilvie-Harris et al., 1995; Teitz et al., 1985). It is suggested that this is may be due to these dancers padding their toes more carefully due to the preconceived notion that this toe shape is not ideal for pointe shoes, or because they use a tapered toe box shape (Ogilvie-Harris et al., 1995). Without toe padding however, this toe shape was found to have poor alignment in the MTP joints en pointe. A study found that dancers who had a second toe shorter than the first, and third toe shorter than the second in a normal plantar stance, had all three of these toes contact the end of the toe box en pointe. This suggests that the MTP joints may be aligned differently en pointe than in a plantar stance (Tuckman et al., 1991).

If a dancer is balanced en pointe, the first force couple in the body is between the ground reaction force and the force going through the forefoot. The force couples continue at the foot's other joints then into the ankle, knee, and hip joints. If the forefoot has poor alignment, the joint moment in the forefoot will be increased, leading to higher joint moments further up the kinetic chain and requiring the muscles of the forefoot to exert more force to maintain the position. This in turn will impact the muscle forces required to hold the body in position at the midfoot, hindfoot, ankle, knee, and hip.

Each dancer's foot profile is unique, and the placement of their foot inside the pointe shoe is hard to predict, and no relationship between toe shape and pointe shoe injuries has been found (Ogilvie-Harris et al., 1995; Tuckman et al., 1991). Therefore, it has been difficult for manufacturers to design stock shoes that are ideal for every foot (Barringer & Schlesinger, 2021, p. 27) and thereby combating some common causes of pointe shoe related injury.

2.5 Dancer's perceptions of pointe shoes

Several surveys and interviews over the years have been given to dancers to try and understand what they look for in a pointe shoe. One such survey found that dancers rated fit, comfort, and box/platform shape as the top three characteristics of importance, whereas factors such as durability, price, and availability were of lesser importance to dancers (Cunningham et al., 1998). Interviews revealed dancers want their pointe shoes to meet certain ergonomic, aesthetic and convenience needs (Colucci & Klein, 2008). The ergonomic wants include "hugs the arch," "is easy for the foot to manipulate," "allows the dancer to roll through easily", and "molds to the shape of a dancer's foot" (Colucci & Klein, 2008). These ergonomic needs are all dictated by the fit of the shoe. The feeling of a pointe shoe, and how it makes the foot look are a large factor in what drive a dancer to use a particular pointe shoe (Barringer & Schlesinger, 2021, p. 26).

The fit of a shoe dictates dancer’s perceptions of pressure, comfort, control, stability, and the dancer’s ability to feel the floor through the shoe (Barringer & Schlesinger, 2021, p. 27). A study on creating a more comfortable soft technique shoe found that providing a more even pressure distribution on the plantar surface of the foot with a well-designed orthotic was successful in increasing dancer comfort (Miller et al., 1990). If applied to pointe shoes, reducing the number of painful pressure points by more evenly distributing the pressure may increase dancer’s feelings of comfort en pointe.

Feelings of better control over the shoe and increased stability may be achieved by increasing the proprioceptive feedback in a pointe shoe. This may be done through a better fitting shoe with less padding between the foot and the shoe (Squadrone & Gallozzi, 2011). Running shoes with excess cushioning have been shown to dampen proprioceptive signals (Squadrone & Gallozzi, 2011), therefore an excess of thick toe padding may also dampen proprioceptive signals in pointe shoes.

Dancers want their shoes to hug their arch and show their pointed foot well (Colucci & Klein, 2008). When standing en pointe, the foot’s joints contribute about 27.7% of the total plantarflexion movement in ballet dancers, the ankle joint contributing the other 72.3% (Russell et al., 2011). The shoe must therefore be able to articulate the foot’s fine movements so that the extreme range of motion of the foot’s joints can be seen. Motion in as small a joint as the MTP joints should be visible and articulated through the shoe as the dancer also needs to work on demi-pointe (Barringer & Schlesinger, 2021, p. 27).

2.6 Pointe shoe redesigns to address common issues

To address the wants of ballet dancers, pointe shoe manufacturers and independent designers have created shoes that address the ergonomic, aesthetic and convenience needs in pointe shoes. Gaynor Minden is perhaps the largest pointe shoe manufacturer that has made significant changes to the classic pointe shoe. Through years of research, this company developed a synthetic plastic shank and toe box that lasted about 175,000 more loading cycles than any other pointe shoe (Cunningham et al., 1998). To address the need for a more customized fit, an independent designer created 3D-printed custom pointe shoes for dancers in Israel using a scan of dancer’s feet (Neeman, 2019). It appears, however, that the technology and design have not been commercialized and are therefore not accessible for most dancers. Act'ble is another 3D printed shoe company that has reimagined the pointe shoe and created a design that can be split in pieces so individual parts can be replaced when necessary (*New Generation Ballet Pointe Shoe*, n.d.). As of the time of writing, this company is offering pre-order on their shoes. These shoes do not maintain the aesthetic of classic ballet shoes, and therefore may be considered a training shoe and not a performance shoe. Other independent designers have proposed designs to improve upon pointe shoes, one student from the University of Waterloo patented a design that utilises a leaf spring under the metatarsophalangeal joint to provide additional support to this joint (Elve, 1999). Another patented design by a high school student implemented a boot like design to provide extra support to the foot and ankle (Colucci & Klein, 2008).

All these designs address an issue with pointe shoes however many have not yet come to market, are not accessible to all dancers, or have not addressed all the issues that are relevant to dancers. There are still characteristics of pointe shoes that ballet dancers want that may be more easily addressed with the use of fit accessories than at the shoe manufacturing level. This approach allows dancers to continue to purchase the brand and model they believe works best for them and improve the shoe from there.

2.7 Toe padding and pointe shoe fit accessories

Dancers have turned to fit accessories and toe padding to help improve the fit of their pointe shoes, relieve concentrated areas of high normal contact pressure, and improve their forefoot alignment. These fit accessories range from gel toe pads with a thin fabric cover that are designed for pointe shoes, to toe spacers, lamb's wool, and to common household items such as paper towel and kitchen sponges (Barringer & Schlesinger, 2021). Dancers place these materials around and between their toes in a manner that feels good to them.

There is evidence that well placed toe padding helps redistribute the pressure on the forefoot more evenly (Teitz et al., 1985). A study recording the pressure on the first MTP joint and the distal ends of the first and second toes of thirteen experienced baller dancers on full pointe found that if a toe cap is placed on the tip of a short second toe, the pressure across the first two toes is more evenly distributed. With a toe cap, the short second toe can make contact with the end of the toe box and bear some of the ground reaction force, reducing the load on the hallux (Teitz et al., 1985), while theoretically keeping the metatarsals aligned.

A variety of orthotics with varying materials and shapes have also been tested in soft ballet technique shoes. A professional male ballet dancer completed grand jetés (split leaps), landing on one leg in a regular soft technique shoe, and eleven soft technique shoes modified with differing orthotics. The pressure distribution across his landing foot and the ground reaction forces were recorded for each orthotic. The orthotics were made of differing amounts of padding under the heel, arch, metatarsals, and toes. All the orthotics tested created a more even plantar pressure distribution compared to the shoe without the orthotics (Miller et al., 1990). The most successful orthotic provided thicker cushioning under the arch, compared to under the toe. When using this insole in soft ballet shoes, the pressure under the medial arch was increased, and the pressure at the lateral arch, heel, and the first two metatarsals and toes was decreased (Miller et al., 1990). The use of an orthotic in a soft ballet shoe successfully redistributed the plantar pressure more evenly.

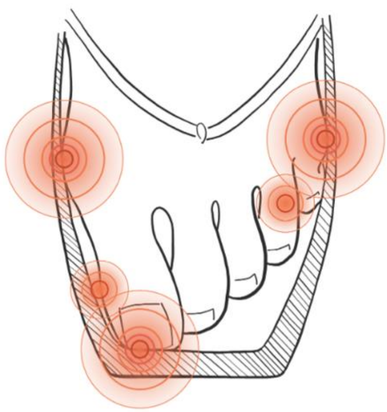
Perhaps the most common type of toe padding for pointe shoes is the gel toe pad. These traditional toe pads provide a uniform layer of gel around the toes as seen in Figure 2-2. This helps form the bridge of material between the foot and shoe that is needed in some areas to create a more even pressure distribution; however the pressure is only increased in areas where there is already high normal contact pressure as illustrated in Figure 2-3. People sometimes instinctively add additional padding to areas of the feet where painful pressure points have formed. Although this may help relieve the pain related to a hard material rubbing against the soft tissue of the forefoot, it increases the normal contact pressure at this point due to the extra layer of material between the foot and shoe in an area that already had adequate contact area.

Figure 2-2

Front and top view of gel toe pad

Figure 2-3

Points of contact dancers may experience between the inner pointe shoe and the foot (PerfectFit Pointe - The Design, n.d.)



An ideal way to increase the contact surface area between the foot and the shoe, specifically in areas that require it, as well as help the forefoot maintain good alignment may be the use of custom molded toe pads. These toe pads fill the empty space within a pointe shoe, taking the shape of the toes and the inner shoe. If molded while the foot is in good alignment, it will guide the forefoot into this alignment whenever the pointe shoe is in use. These toe pads are molded with a putty that is fluid enough to naturally fill the negative space within the shoe before solidifying. This allows additional material to be added to areas that require a bridge between the foot and the shoe, such as the distal end of the fourth toe, and less material is added to areas that already have sufficient foot and shoe contact, such as the medial side of the first

MTP joint (*PerfectFit Pointe - The Design*, n.d.). This concept is depicted in Figure *2-4*, and the custom molded toe pads are shown in Figure *2-5*. A study on custom molded toe pads has already shown they can significantly reduce the toe deviation angle of the hallux, promoting better alignment in the forefoot (Salzano et al., 2019). This study used X-ray images to measure the abduction angle of the 1st MTP joint of ten, professional, female, ballet dancers with a custom molded toe pad and a standard toe cap. Its use was also found to reduce dancer's perceptions of discomfort during dance (Salzano et al., 2019).

Figure 2-4

The theoretical inside of a pointe shoe with a custom molded toe pad (PerfectFit Pointe - The Design, n.d.)

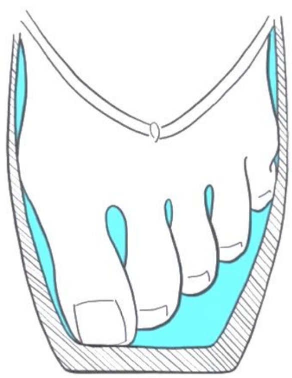
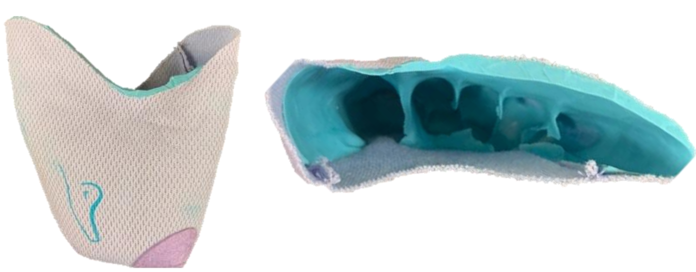


Figure 2-5

Front and top view of custom molded toe pad



A toe pad that creates a greater contact surface area between the foot and the inside of the shoe may have positive impacts on the dancer. Firstly, the increased contact surface area may create a more uniform normal contact pressure distribution. This may be perceived by the dancer as a decrease in pressure points, and an increase in comfort. Secondly, the increased contact surface area may create an increase in proprioceptive feedback which may translate as an increased feeling of stability, control, and ability for the shoe to articulate the foot's fine movements. To aid in the prevention of overuse injuries, the impact of toe padding on the forefoot in pointe shoes must be better understood so more informed decisions regarding dancer's foot health can be made. There is only one study examining custom molded toe pad's impact en pointe dancing, and it does not address pressure distribution.

2.8 Knowledge gap

Dancing en pointe can be uncomfortable or painful due to injuries caused in part by the unnatural loading on the foot. The forefoot is primarily soft tissue and small, non-load bearing bones; but when dancing en pointe, the forefoot must bear most of the body's weight. These high loads distributed on the forefoot by a tight-fitting shoe often causes concentrated areas of high pressure leading to overuse injuries (Torba & Rice, 1993) and painful surface ailments (Ayoub, 2021). Each dancer's foot profile is unique; therefore, it is impossible for manufacturers to design a shoe that matches each dancer's foot. Toe padding is used to protect the forefoot from pressure points (Barringer & Schlesinger, 2021, pp. 29–30) and could be a realistic way for dancers to achieve a better fitting shoe. Very little is known regarding the impact different toe pad designs have on the normal contact pressure on the forefoot as well as dancer's perceptions of their impact (Fong Yan et al., 2011). There appears to only be one study that compares a kinematic variable between types of fit accessories in pointe shoes (Salzano et al., 2019), and one study that compares a kinetic variable between a pointe shoe with no fit accessories, and a pointe shoe with a standard fit accessory (Teitz et al., 1985). Both these studies have recommended that further investigation be completed regarding fit accessory's impact on injury in ballet dancers.

Understanding how toe padding impacts dancing ballet en pointe will allow dancers, dance teachers, pointe shoe fitters, pointe shoe designers, and dance health professionals a better understanding of key factors that affect dancer's foot health. This understanding may lead to a decrease in overuse injuries and surface aliments, resulting in longer and healthier careers for professionals. These same findings may create a more accessible path for recreational dancers to enjoy pointe work, as the amount of discomfort they experience while dancing en pointe may decrease. The effects of toe padding on dancing ballet en pointe must be researched so that proper toe padding can be designed and utilised, leading to a more accessible activity, as well as longer and healthier ballet careers.

3 Purpose and hypothesis

The purpose of the study was to measure the normal contact pressure on the forefoot during rises en pointe with gel toe pads, custom molded toe pads, and the participant's choice of fit accessories to understand how pressure distribution is impacted by fit accessories in experienced, female, ballet dancers. The secondary purpose of the study was to determine how the use of different types of fit accessories were perceived by dancers in terms of pressure, comfort, control, stability, articulation, and overall performance.

It is hypothesized that the custom molded toe pads will provide a more even normal contact pressure distribution across the forefoot, compared to the participant's usual fit accessories and the generic gel toe pad. This may be perceived by the dancer as a decrease in pressure points, and an increase in comfort. Due to this potentially providing an increase in proprioceptive feedback, dancers may also experience an increased feeling of stability, control, and ability for the shoe to articulate the foot's small movements. Dancers may perceive their usual fit accessories to perform better than the generic gel toe pads, due to the familiarity they have with the feeling of dancing with them.

4 Methods

4.1 Participants

This was a cross sectional, repeated measures study. Participants were recruited from ballet schools and ballet companies in the greater Montreal area. Thirty female participants between the ages of 15 and 35 were recruited. All dancers had at least three years of experience dancing en pointe and were free from any musculoskeletal injuries in the lower extremities. All participants were actively dancing at least three hours per week.

To calculate the sample size, a power of 0.8, an alpha level of 0.05, six measurements, and an effect size of 0.2, were used. It was determined that thirty participants were required for the repeated measures ANOVA. The effect size assumes a small/medium effect as other similar studies found varying effect sizes (Salzano et al., 2019; Teitz et al., 1985).

A research ethics certificate was obtained through McGill's Research Ethics Board III (reference number 22-08-007) and is displayed in Appendix Figure 9-1 in the Appendices. Participants were given the ethics consent form to read and sign before any data collection took place. The consent form is displayed in the Appendices in Appendix Figure 9-2. Participant recruitment and data collection took place between September 2022 and January 2023. The participants' characteristics are outlined in Table 4.1. See Section 4.5.1 for additional information on the "Recreational" and "Elite" groups.

Table 4.1

Mean (standard deviation) for participant characteristics

	All dancers	**Recreational dancers**	**Elite dancers**
Age (years)	21 (5)	26 (5)	19 (3)
Height (m)	1.64 (0.50)	1.63 (0.42)	1.65 (0.53)
Weight (kg)	51.99 (5.91)	51.06 (5.46)	52.45 (6.20)
Ballet experience (years)	13 (4)	14 (5)	13 (3)
Pointe experience (years)	8 (3)	9 (4)	7 (3)

4.2 Instrumentation

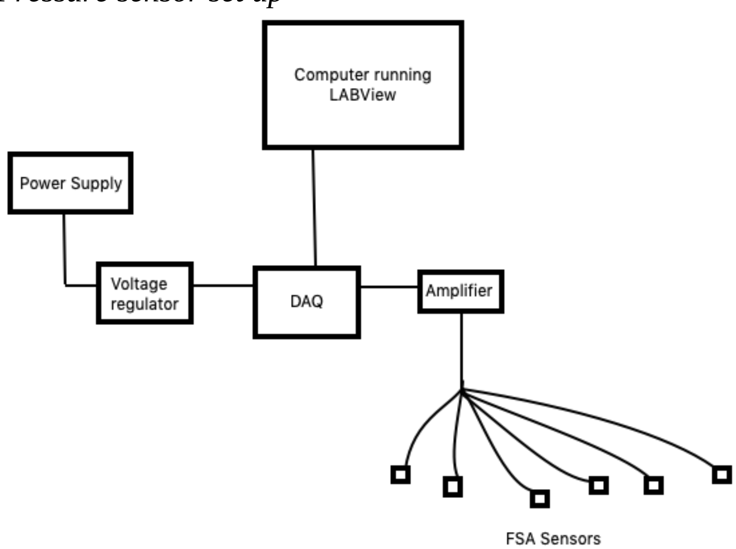
4.2.1 FSA pressure sensors

Force Sensor Application Array (FSA) sensors were selected to be used due to their availability, their small size, and their durability. The FSA sensors (Vista Medical, Winnipeg, Manitoba) are small, flexible, and thin, and do not get in the way of the dancer's natural movement. This was a required characteristic due to the small space inside a pointe shoe. The wires were also thin and flexible and pass out of the shoe easily. The FSA sensors are coated in Teflon which provides additional durability. They measured approximately 170mm by 150mm and had an active sensing area of 64 mm by 64 mm.

The sensors measured force at a frequency of 1000 Hz. A 32-channel amplifier was designed in PCB Artist (V 4.0, Aurora, Colorado) that allowed the sensors to collect data in the appropriate range (data collection occurred primarily between 0 kPa and approximately 3000 kPa) (Le Ngoc, 2012; Teitz et al., 1985). The FSA sensors were connected to the amplifier circuit board using a ribbon cable. This was then connected to a data acquisition device (National Instruments cDAQ-9174, Austin, Texas) and connected to the computer running LabVIEW (Version 11.0, National Instruments, Austin, Texas) via a USB cable. The data acquisition device was powered with 5V and a voltage regulator was added in series between the power supply and the data acquisition device. The experimental set up is shown in Figure 4.1.

Figure 4-1

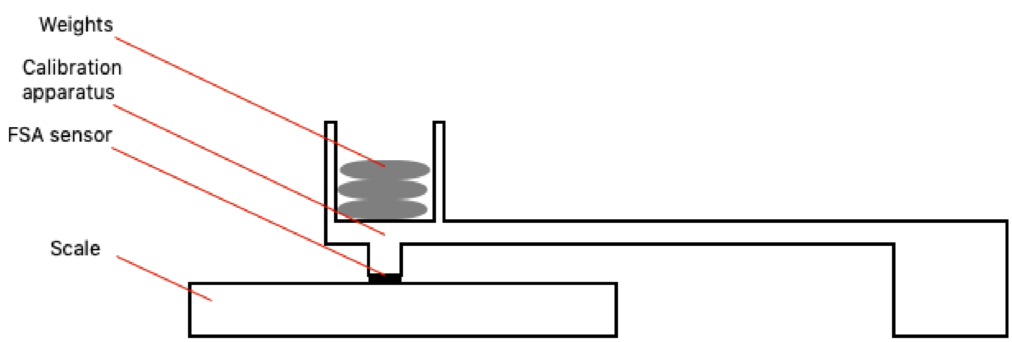
Pressure sensor set up



The output voltages of the piezoresistive FSA pressure sensors were recorded throughout the trials as they are proportional to the force applied to the sensor. The resistance of the sensors change based on the force applied, therefore if the input voltage is held constant, applied force corresponds to the voltage output of the sensors. To calculate the relationship between applied force and output voltage, the sensors were calibrated. An apparatus was constructed that transferred weight to the active sensing area of the sensor. To begin, the unweighted output voltage of a sensor was recorded. The apparatus was then placed on the sensor, and the corresponding output voltage and force were recorded. Weights of 1kg were then incrementally placed on the apparatus and the output voltage and force on the sensor were recorded each time, until 7kg was resting on the apparatus. The calibration set up is shown in Figure 4-2. This method is in accordance with previous methods of calibrating the same sensors (LeNgoc, 2012).

Figure 4-2

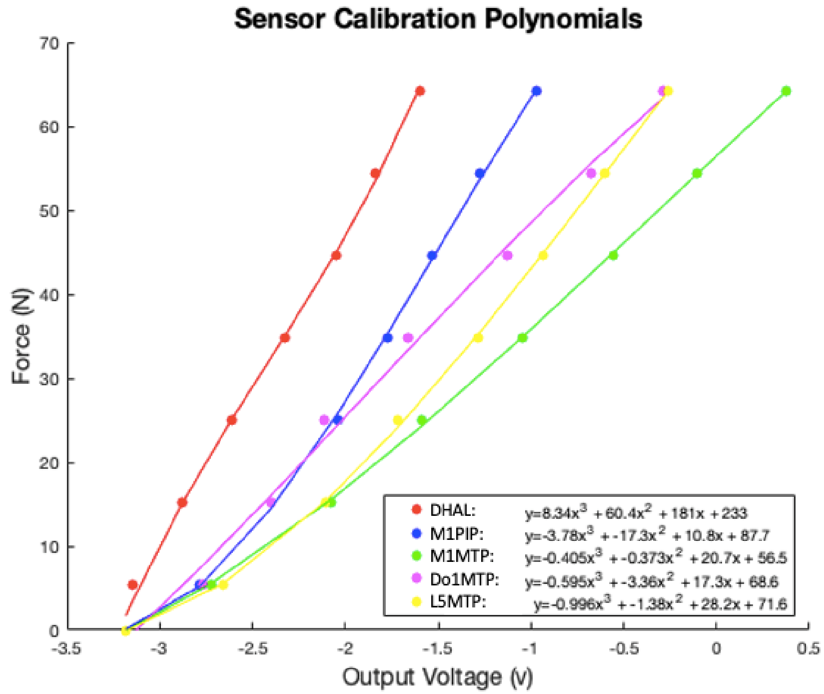
Calibration set up



Using these known forces and output voltage points, a cubic polynomial was found that described the relationship between output voltage and force for each sensor. This cubic polynomial was then used to calculate force from output voltage during the study. The polynomials are shown in Figure 4-3. For each sensor, a high correlation between force and output voltage was found. The R^2 value was greater than 0.98 for all the sensors.

Figure 4-3

Polynomials for sensor calibration



4.2.2 Toe pads

The participants danced with three different toe padding conditions: gel toe pads, custom molded toe pads and the participant's usual fit accessories. The gel toe pad and an example of the custom molded toe pads are shown in Figure 4-4.

Figure 4-4

Gel toe pads used in data collection (left) and example of custom molded toe pads used in data collection (right)

The model of gel toe pad selected (CG-PAD2, Sansha, Paris, France) is a very common type of pointe shoe toe pad. The custom molded toe pad (PerfectFit Pointe, Menlo Park, USA) is a putty like material that hardens to a rubbery consistency and fills the empty space within the pointe shoe. The molding process is described in Section 4.3.1. The participant's usual fit accessory condition was referred to as the "Participant's choice" condition. The toe padding used in the Participant's Choice condition is outlined in Table 4.2. Note that dancers sometimes used multiple fit accessories at once, so the middle column sums to more than 30 (the number of participants).

Table 4.2

Fit accessories used in participant's choice condition

Fit accessory used by participant(s)	Number of times used by a participant
Gel or foam pad of any type (with or without toe spacers)	19
Lamb's wool	4
Tape	4
Dishcloth	2
Adhesive gel stickers	2
Toe spacers (nothing else)	1

4.3 Experimental protocol

4.3.1 Participant preparation

Testing took place at the Biomechanics and Performance Analysis Lab in McGill Universities' Currie gymnasium. Upon arrival in the lab, anthropometric measures were taken of the participant. These included their height, weight, foot length and foot width. Participants were then given an initial questionnaire that gathered information regarding their history with ballet, how much they actively dance, the pointe shoes they usually wear, their perceptions of discomfort they usually feel while dancing en pointe, and their toe shape. Their toe shape was classified based on the length of their second toe. Participants were given diagrams and asked to circle which one most closely resembled their toe shape while in a normal stance. One diagram showed a foot with a second toe of equal length to the first, one showed a foot with a second toe shorter than the first, and one showed a foot with a second toe longer than the first. This survey can be seen in Appendix Figure 9-3 in the Appendices.

The pressure sensors were fixed to anatomical landmarks on the left forefoot with medical tape. These locations can be seen below in Figure 4-5 and are summarized in Table 4.3. For clarity, the sensors will be referred to as their abbreviated locations which are also displayed in Table 4.3.

Figure 4-5

Pressure Sensor Locations

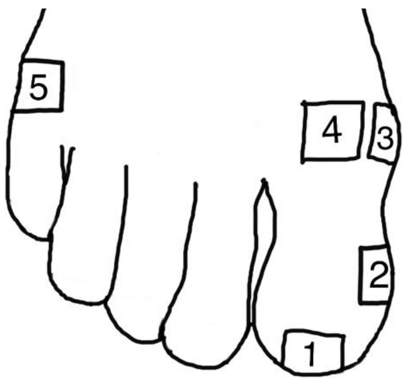


Table 4.3

Pressure sensor locations

Sensor Number	Location	Abbreviation
1	Distal end of hallux	DHAL
2	Center of medial side of 1st interphalangeal joint	M1PIP
3	Medial side of head of 1st metatarsal	M1MTP
4	Dorsal side of head of 1st metatarsal	Do1MTP
5	Lateral side of head of 5th metatarsal	L5MTP
6	Edge of outer sole of the shoe, underneath the heel	N/A

One type of toe pad was then placed on the feet, and the participant put their pointe shoes on like they normally do. Participants were instructed to use a pair of pointe shoes that were broken in, but not worn out. A sixth sensor was then taped to the outside of the shoe, under the heel at the end of the outer sole so that the heel and ground contact could be detected. The sensor's wires were fixed to the leg with a Velcro strap above the knee so that the wires did not interfere with the movement of the feet. The dancer was then given time to warm up their feet and become familiar with the experimental set up and toe pad condition.

The custom molded toe pads were molded before completing the data collection in this padding condition. Participants took one of their pointe shoes off. The two putties were then mixed by the researcher until they were thoroughly incorporated, most of the putty was then placed on the top and sides of their toes, and a small amount underneath their toes. A fabric pouch was then stretched over their toes, and a plastic pouch was placed over top of that. The participant then put their foot into their pointe shoe, so both shoes were on, and went to the barre. At the barre, they completed a series of slow rises, tendus, and balanced en pointe. The excess putty seeped out the top of their shoe. They were instructed to ensure they were in correct alignment when en pointe during the molding process. After 7-10 minutes, the putty had solidified, retaining the shape of their toes en pointe. This is in accordance with the molding instructions provided by PerfectFit Pointe. The same process was repeated on the other foot. For the left foot, the toe pad was molded on top of the sensors so that they would detect a realistic normal contact pressure between the foot and the toe pad and not create pressure points themselves. After data collection with this condition, the toe pads were carefully removed from the feet, and the plastic pouch was discarded. The excess putty that seeped over the top of the shoe was then trimmed. The moulding process is outlined below in Figure 4-6.

Figure 4-6

Molding of custom toe pad

1) Unmixed putty and fabric pouch

2) Foot with sensors secured

3) Mixed putty is placed on the foot

4) Fabric pouch stretched over putty

5) Plastic pouch on foot to protect shoe from soft putty

6) Pointe shoe placed on foot

7) En pointe molding (excess putty leaves shoe)

8) Solidified toe pad untrimmed

4.3.2 Tasks

Participants completed three different ballet steps and a flat foot stand. They completed each of the ballet steps six times and completed all the tasks in a random order with each toe pad type at the barre. Participants were offered rosin for their pointe shoes, and it was applied if they found the floor slippery. Music was played for each step so that participants completed the steps with similar timing. All music was in 4/4 time. The steps and tempo of the music are outlined in Table 4.4. Visual depictions of the ballet steps can be found in Appendix Figure 9-4, Appendix Figure 9-5 and Appendix Figure 9-6. When all the steps were completed, the participant took their pointe shoes off, and the next set of toe pads was put on. The order in which they used the toe pad was randomized. This process was repeated for all three conditions.

Table 4.4

Summary of ballet steps, music, and tempos

	Rises	**Échappés**	**Balance in retiré**	**Normal Stand**
Song title	Stepping Up to Pointe in 2/4 – Slow Polka	Releve/Echappe 2 (Excerpt from Giselle)	Pirouette 1 ¾ - Grand Pas Espagnole (From "Raymonda", Act 2)	No accompaniment
Artist	Craig Wingrove	A. Adam & Rob Thaller	Craig Wingrove	
Tempo (bpm)	54	80	66	
Preparation	1^{st} position facing barre	5^{th} position right foot devant, facing barre	5^{th} position right foot devant, facing barre	
Count 1	Begin rise to full pointe	Échappé to 2^{nd}	Relevé on left and bring right to retire	Feet together and parallel, hold for 5s
Count 2	Continue rise to full pointe in 1^{st}	Hold	Hold (lift hands off barre)	
Count 3	Begin lowering	Hold	Hold (hands off barre)	
Count 4	Continue lowering to 1^{st}	Close left foot devant	Close 5^{th} right foot devant	

Participants completed rises to full pointe, balances in retiré and échappés so that a wide range of basic ballet movements could be studied. Rises to full pointe are a slow and controlled movement that require a dancer to demonstrate their strength, flexibility, and control en pointe. Balances in retiré are a balance on one foot, dancers often place all of their weight on one foot en pointe so it was important to understand what was occurring during this type of movement. Finally, échappés to second position were chosen as these are a fast spring onto pointe which allowed a higher impact step to be studied.

4.3.3 Surveys

When all the ballet steps were completed with one toe pad condition, the participants then completed the "End of trial survey," shown in Appendix Figure 9-7 in the Appendices. For participants to provide accurate ratings of the toe pads that were not influenced by the feeling of the pressure sensors inside the shoes; the sensors were removed and participants danced again with each toe pad condition before completing the survey. Questions on the "End of trial survey," were asked using both a Likert scale and a Visual Analog scale. The Likert scale requested participants circle values between 1 and 5, with 1 being a negative score and 5 being a positive score. Particicants rated the following variables: overall comfort, overall pressure, overall control, overall stability, ability for the shoe to articulate the movements of the foot, and overall performance. The Visual Analog scale was 10 cm long and the location of the participant's markings along the lines were recorded to the nearest millimeter. Participants were asked to provide ratings for pressure on the right and left feet, comfort for the right and left feet, and stability for the right and left sides. Participants rated these variables after dancing with each type of toe pad and gave separate ratings for each. The ratings for these variables were used as dependent variables in the statistical analysis.

4.4 Data Processing

4.4.1 Pressure data

The output voltage data was exported into MATLAB (R2022a, MathWorks, Inc., Massachusetts, U.S.A.) and was filtered using a 4^{th} order Butterworth filter and a 14 Hz cut off frequency (Le Ngoc, 2012). Force was then found from the voltage data using the process outlined in Section 4.2.1. Pressure was calculated using the known active sensing area of 6.4 mm x 6.4 mm and the following equation:

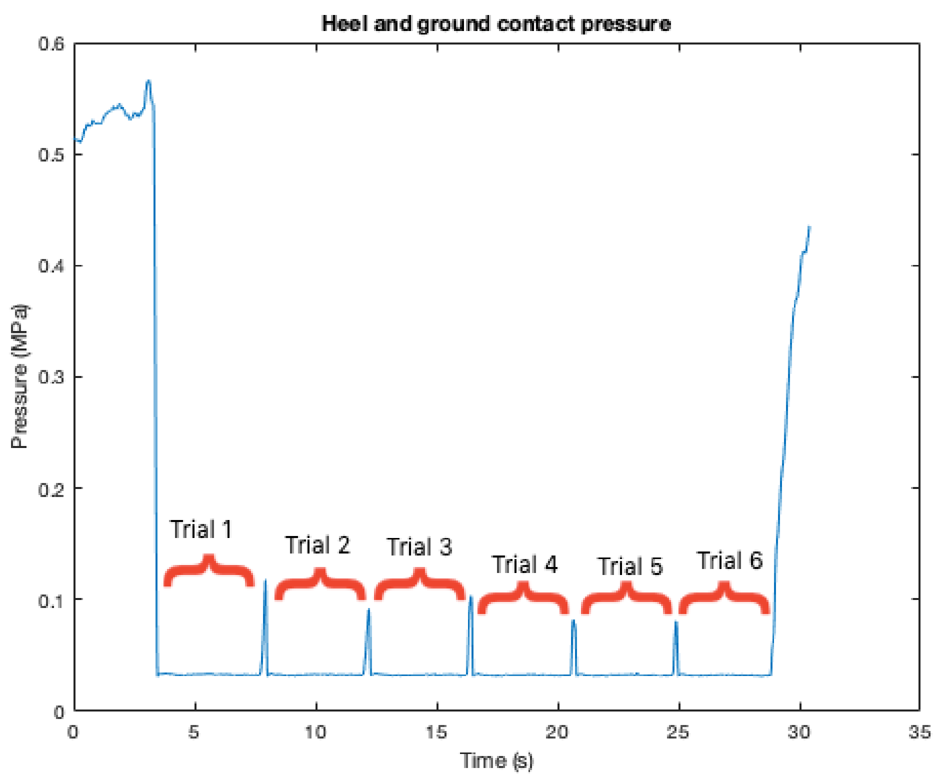
$$P = \frac{F}{A}$$

Where P is pressure in Pa, F is force in N, and A is cross sectional area in m^2.

Each data file for the ballet steps contained six trials, as the participant completed six rises, échappés, or releves to retiré in sequential motions (as is done in a ballet class). To determine where the start and end of each rise occurred, the data recorded by the sensor placed under the heel was plotted. Peaks in this pressure data represent when the heel was in contact with the ground. The end of the first motion/beginning of the next motion was defined as the point in time where the heel and ground contact pressure peaked. An example of this plot is displayed in *Figure* 4-7 with the location of the trials highlighted. After the data was separated into individual trials, it was normalized to the participant's body weight, then time normalized to 101 data points using a cubic spline. This was completed for all sensors and all ballet steps.

Figure 4-7

Event detection plot using heel and ground contact pressure



The movements of rises, balances in retire, and échappés to second position were divided into separate phases. Visual representations of these movements can be seen in Appendix Figure 9-4, Appendix Figure 9-5, and Appendix Figure 9-6. For rises, participants rose for the first two counts and lowered for the last two counts. The motion was therefore divided into two phases: the rise, and the lower, with the balance being the dividing event. The balance in retire motion was broken down into three portions of motion. This motion began in the plié position, then the dancer relevéd into retire and held the pose for two counts before returning to plié. The motion's portions were the first plié, the balance in retiré, and the second plié. Similarly, the échappé motion began and ended with a plié so the motion was divided into three portions, the first plié, the échappé, and the return to plié. It was not known from the plots exactly when these phases occurred, therefore it was estimated based off the timing dancers were instructed to use. Detailed timings for all the motions can be seen in Table 4.4. Throughout the analysis, the movements are referred to in these portions of motion.

For the flat foot normal stand trial, the first and last second was discarded and the average pressure was calculated over the remaining data. This value was then normalized to body weight and used as the dependent variable.

4.4.2 Principal Component Analysis (PCA)

A PCA is an analysis that is used to describe the variability of related variables. This method of analysis reduces the dimensionality of the data and identifies important features. It also allows the waves to be compared continuously, as opposed to selecting discrete moments such as waveform maximum values (Deluzio & Astephen, 2007).

The amplitude and time normalized normal contact pressure data collected during each ballet step, for all participants (n=30), all trials (n=6), and all conditions (n=3) were compiled into one matrix (X) for each sensor and each ballet step. A principal component analysis (PCA) was then completed for each matrix containing the data for each sensor during each ballet step using MATLAB (R2022a, MathWorks, Inc., Massachusetts, U.S.A.). A total of fifteen (5 sensors, 3 ballet steps) PCAs were completed.

A covariance matrix was calculated from the original data matrix (X) and the eigenvectors and eigenvalues were extracted from this covariance matrix. The eigenvectors (U) are the principal components (PC) and represent unique waveform characteristics. The eigenvectors make up a transformation matrix that was then used to find a new matrix of *PC-scores* using the following equation:

$$PC\text{-}Scores = [X - \bar{X}]U$$

There are *PC-scores* for each row in the original data matrix, meaning *PC-scores* are available for each pressure waveform in the original matrix. A feature of variation was identified for each PC: a change in magnitude, a difference operator, or a phase shift. *PC-scores* represent each wave's variability from the mean for one of the features of variation (Deluzio & Astephen, 2007). The 5th and 95th percentile of each set of PCs were plotted to determine the type of feature of variation. The feature of variation they describe was identified through visual inspection of the plots. Waveforms were determined to be magnitude changes if the 5th and 95th percentile plots were the same shape but different magnitudes. Waveforms were determined to be difference operators if the 5th and 95th percentile plots were different ranges. Finally, waveforms were determined to be phase shifts if the 5th and 95th percentile plots were the approximate same shape and magnitude but offset in the x-axis.

PC-scores were used as the dependant variable in the statistical analysis. The percent variance explained by each PC was summed until 90% was reached, then no further PCs were analysed. The number of PCs that were analysed for each ballet step are displayed in Table 4.5.

Table 4.5

Number of PCs to be studied at each sensor location for each ballet step

	DHAL	**M1PIP**	**M1MTP**	**Do1MTP**	**L5MTP**
Rises	2	3	4	5	4
Balance in retiré	2	2	2	2	1
Échappés	2	3	2	2	1

4.5 Statistical analysis

SPSS statistical software (V27, IBM, Chicago, USA) was used for the statistical analysis. An average *PC-score* from the six trials was found for each participant for each toe pad condition, so there were three *PC-scores* for each participant during each ballet step, one for each condition. Repeated measures ANOVA compared *PC-scores* between toe pad conditions. Separate ANOVAs were conducted for each sensor and each ballet step. An additional ANOVA was run on the flat foot normal stand data. Thirty-eight repeated measures ANOVAs were performed in total (sum of all values in Table 4.5 plus one more for the flat foot normal stand). The data was confirmed to meet the assumptions of the repeated measures ANOVA and the partial eta squared effect size was also calculated for each comparison. A small effect size was considered greater than 0.2, a medium effect size greater than 0.13 and a large effect size greater than 0.26 (Cohen 1988, p. 413-414). The Bonferonni correction was used to determine the pairwise significance of results. The significance level was set to alpha < 0.05.

Friedman tests were also run on dancer's ratings for overall comfort, overall pressure, overall control, overall articulation, overall stability, pressure on the right foot, pressure on the left foot, comfort for the right foot, comfort for the left foot, stability on the right side, and stability on the left side. Wilcoxon tests were then performed on any significant Friedman tests to determine pairwise differences. This was performed to determine if there were significant differences between dancer's ratings of these variables across toe pad conditions. Kendall's W was calculated as the effect size, less than 0.3 was considered a small effect, 0.3-0.5 was considered a medium effect, and larger than 0.5 was considered a large effect.

4.5.1 Secondary variable analysis

After data collection, it was clear that dancers fell into two categories for training, those that dance professionally or were in a pre-professional program, dancing 20 to 40 hours per week, and those that dance recreationally only 3 to 10 hours per week. No participants danced 11 to 19 hours per week. Therefore, it was determined that there may be a distinction in the way these participants dance en pointe and they were categorized into two groups, "recreational," and "elite." There were 10 participants in the recreational category and 20 participants in the elite category.

Participants were also categorized after data collection based on their toe shape. The length of the second toe may impact the way in which dancers interact with their pointe shoes so it was determined to potentially be an important distinction. Dancers with a second toe shorter than the first were in the “shorter” group, and dancers who had a second toe of equal length or longer than their first toe were in the “equal/longer” group. Their toe shape was determined using a self-assessment displayed in Appendix Figure 9-3 in the Appendices. There were 16 participants in the “shorter” group and 14 participants in the “equal/longer” group. A description of variables is shown in Table 4.6.

Repeated measures factorial ANOVAs were run on the data to determine if these additional sources of variation, or secondary variables, impacted the relationships between *PC-scores* from the pressure waves and toe pad conditions. Separate repeated measures factorial ANOVAs were run for each of the secondary variable groups: toe shape (shorter vs. equal/longer) and level of training (recreational vs. elite). Main effects (toe pad and secondary variable), interactions and effect sizes were examined. Bonferonni’s correction was again used to determine the significance of pairwise comparisons.

Several PCAs did not pass Levene’s test of equality of variances during this analysis. A Yeo-Johnson transform was run on the data that did not meet this assumption of the ANOVA. A Yeo-Johnson transform was chosen due to the negative values in the *PC-Scores* data set (Yeo & Johnson, 2000). The repeated measures factorial ANOVAs were then completed after the data was transformed to meet the required assumptions.

Table 4.6

List of variables

	Variable	Type	Scale	Definition
Primary Variables	Principal component scores	Dependent variable	Continuous	-PCs describe the variability within the normal contact pressure data set
	Dancer's perceptions of toe pads	Dependent variable	Ordinal	-Likert scale rating of comfort, fit, control, stability, articulation, and overall performance (1-5) -VAS scale of ratings of comfort, control, stability, and pressure on both feet (0-100)
	Toe pad type	Independent variable	Categorical	-Custom molded toe pad -Gel toe pad -Participant's usual fit accessories
Secondary Variables	Toe shape	Independent variable	Categorical	0: 2nd toe shorter than 1st toe 1: 2nd toe equal length or longer than 1st toe
	Level of training	Independent variable	Categorical	0: Train less than 20 hours/week 1: Train 20 hours/week or more

5 Results

Upon inspection of the data, it was seen that a number of trials recorded at Do1MTP dropped below zero pascals for four participants so these trials were removed from further processing. During data collection, it was noted that one of the sensors slipped out of place during rises for one participant, so this trial was also removed. A further trial of rises was not exportable from the LabView software and was therefore not included in the analysis. A summary of the number of subjects with complete data sets for each sensor and each ballet step is shown below in Table 5.1.

Table 5.1

Number of subjects with complete data

		DHAL	M1PIP	M1MTP	Do1MTP	L5MTP
Rises	**Custom**	30	30	30	28	29
	Gel	30	30	30	28	29
	Participant's Choice	29	29	29	27	29
Balance in retiré	**Custom**	30	30	30	30	30
	Gel	30	30	30	28	30
	Participant's Choice	30	30	30	28	30
Échappés	**Custom**	30	30	30	28	30
	Gel	30	30	30	28	30
	Participant's Choice	30	30	30	28	30

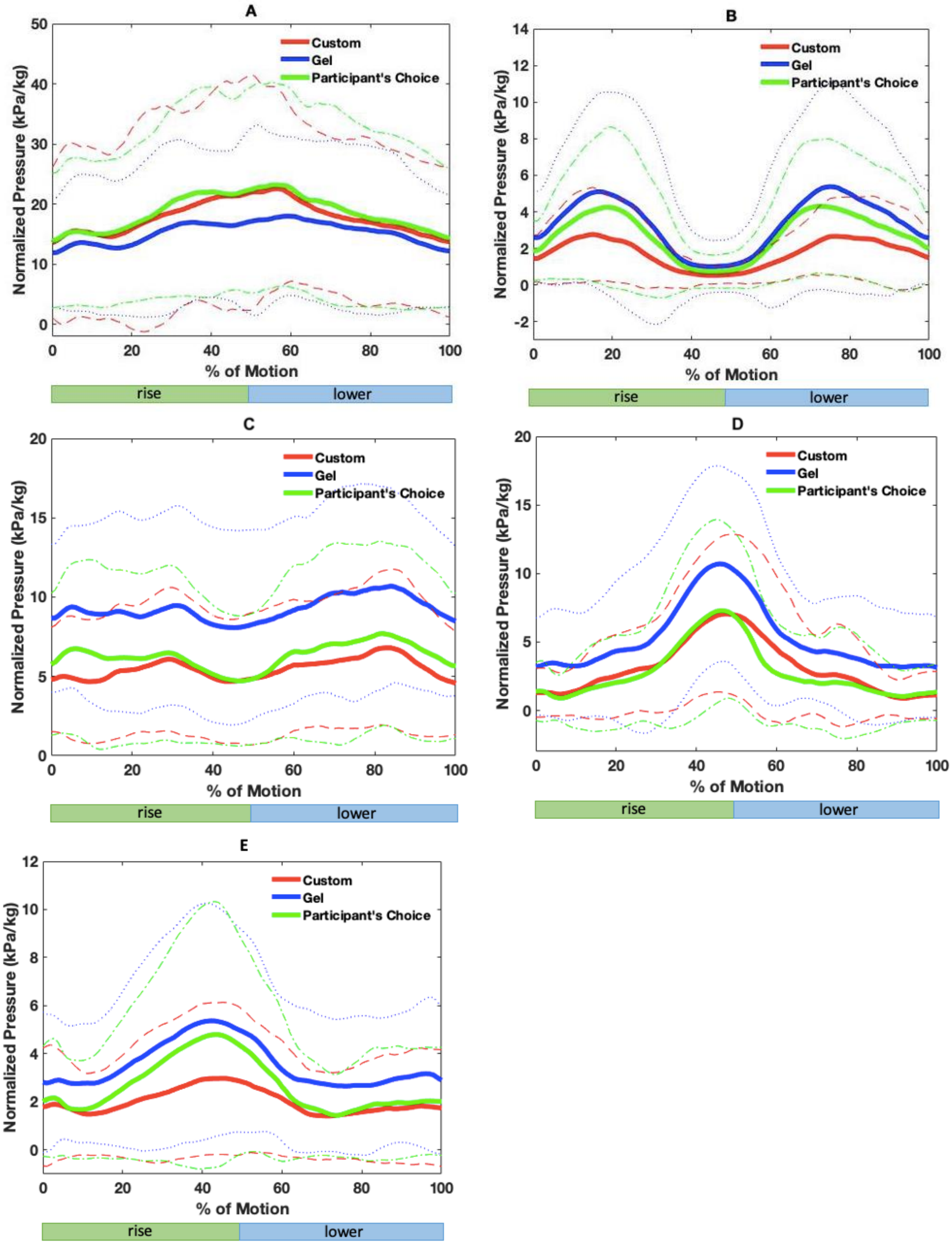
5.1 Repeated measures ANOVAs on principal components and mean pressure

5.1.1 Rises

The mean pressure waveforms (solid lines) and standard deviations (dotted lines) during the rises are displayed in Figure 5-1. The pressure at DHAL (Figure 5-1 A) peaked while the participants were at the top of their rise on full pointe. Pressure at M1PIP and M1MTP (Figure 5-1 B and C) peaked twice, once during the rise portion of motion and once during the lower portion of motion. During the point at which the participant was balanced on full pointe, the pressure at M1PIP and M1MTP was at a minimum. The pressure at both Do1MTP and L5MTP (Figure 5-1 D and E) appeared to peak at the end of the rise portion of motion and the beginning of the lower portion of motion, when participants were balanced on full pointe.

Figure 5-1

Ensemble means (solid lines) and standard deviations (dashed lines) of each toe pad condition during rises recorded at (A) DHAL, (B) M1PIP, (C) M1MTP, (D) Do1MTP, and (E) L5MTP



The interpretations of the PCs as well as the percent variance explained for each sensor during rises are displayed in Appendix Table 9.1. Significant *PC-Score* comparisons for the rises can be seen in Table 5.2 and the descriptive statistics and ANOVA results are in Appendix Table 9.2. During the rises, all sensors had significant *PC1-Scores* except DHAL. *PC1-Scores* represented the overall magnitude and shape (Figure 5-2). M1PIP *PC1-Scores* had a medium effect size and M1MTP, Do1MTP, and L5MTP *PC1-Scores* had large effect sizes. Pairwise comparisons indicated there were significant differences in *PC1-scores* at Sensors 2 and 5 between the custom condition compared to the other conditions. In both cases the custom toe pad had significantly lower *PC1-scores*, indicating a lower pressure was measured throughout the motion (Figure 5-1 B and E). Furthermore, there were significant differences between *PC1-scores* between the gel toe pads compared to the other conditions at M1MTP and 4. The gel toe pads had significantly higher *PC1-scores*, demonstrating higher pressure during the rise (Figure 5-1 C and D). Finally, Do1MTP *PC5-scores* were statistically significant with a medium effect size. This PC was a difference operator (Figure 5-2 G-H). The custom toe pad had significantly higher *PC5-scores* than the participant's choice condition, indicating that the custom toe pad had larger changes in pressure during the rise portion of motion at Do1MTP as this was a difference operator (Figure 5-1 D).

Table 5.2

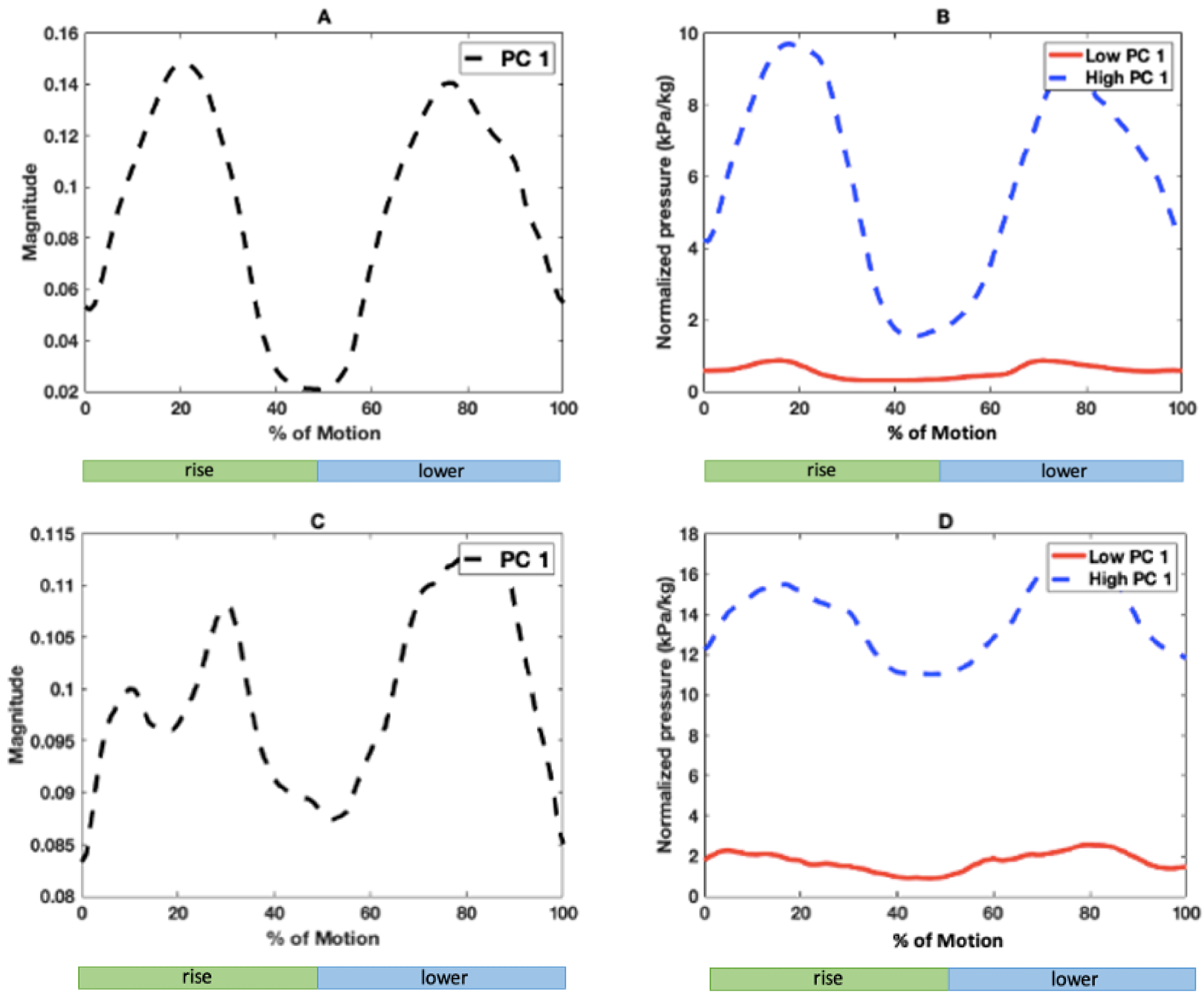
Pairwise comparison of significant PC-scores during rises en pointe

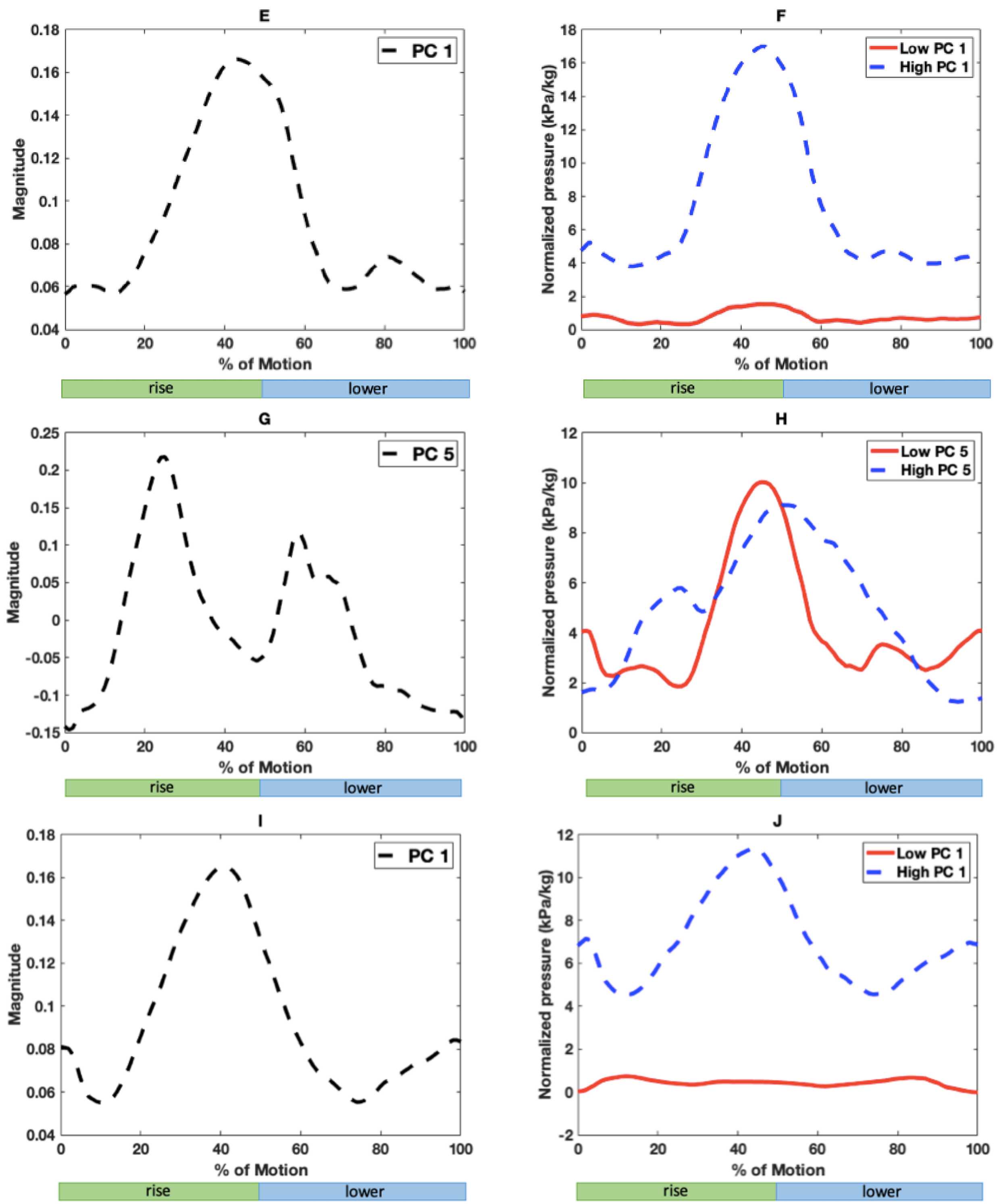
Sensor	*PC*		Gel vs. Custom Significance	Participant's Choice vs. Gel Significance	Custom vs. Participant's Choice Significance	Partial Eta Squared
2	1	Mean *PC-score* difference	1 818	-744	-1 074	0.192
		p	*p*=0.028*	*p*=0.332	*p*=0.017*	
3	1	Mean *PC-score* difference	3 748	-2 966	-782	0.454
		p	*p*<0.001*	*p*<0.001*	*p*=0.400	
4	1	Mean *PC-score* difference	2 704	-2 539	-166	0.317
		p	*p*=0.003*	*p*=0.006*	*p*=1.00	
	5	Mean *PC-score* difference	-0.298	0.032	0.267	0.146
		p	*p*=0.141	*p*=1.00	*p*=0.010*	
5	1	Mean *PC-score* difference	1 469	-455	-1 014	0.317
		p	*p*<0.001*	*p*=0.221	*p*=0.013*	

Note. Significant results are indicated with an asterisk. The Bonferonni test was used for determining pairwise significance.

Figure 5-2

Significant principal components (PC) during rises at (A) M1PIP, (C) M1MTP, (E and G) Do1MTP, and (I) L5MTP. To assist with interpretation, a subset of participants with high and low PC-Scores were plotted next to their corresponding PC. This was done at (B) M1PIP, (D) M1MTP, (F and H) Do1MTP, and (J) L5MTP



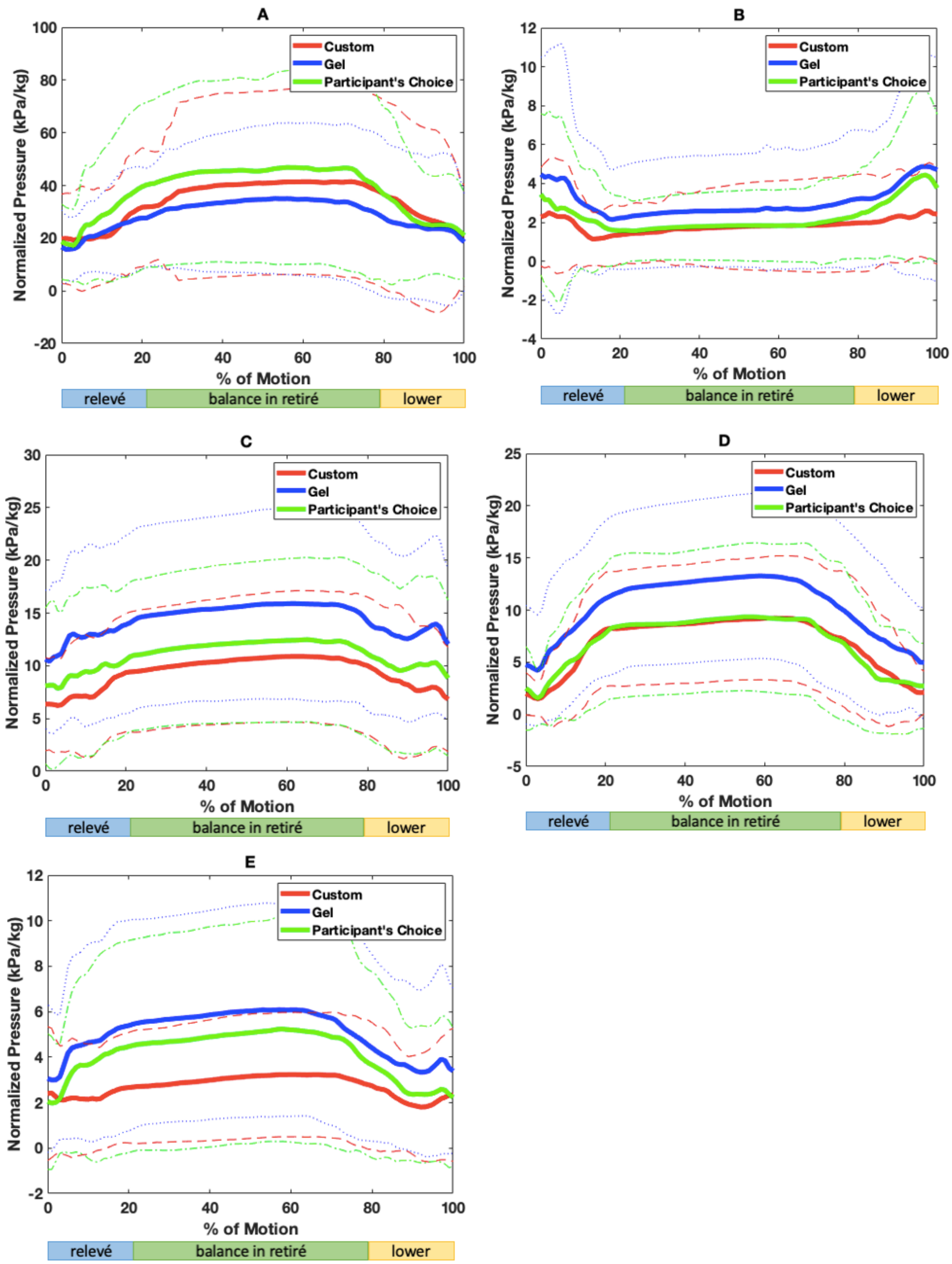

E
PC 1
Magnitude
% of Motion
rise
lower
F
Low PC 1
High PC 1
Normalized pressure (kPa/kg)
% of Motion
rise
lower
G
PC 5
Magnitude
% of Motion
rise
lower
H
Low PC 5
High PC 5
Normalized pressure (kPa/kg)
% of Motion
rise
lower
I
PC 1
Magnitude
% of Motion
rise
lower
J
Low PC 1
High PC 1
Normalized pressure (kPa/kg)
% of Motion
rise
lower

5.1.2 Balance in retiré

The mean pressure waveforms (solid lines) and standard deviations (dotted lines) during the balances in retiré are displayed in Figure 5-3. During the balance portion of motion when the participants were on full pointe, the pressure at DHAL, M1MTP, Do1MTP and L5MTP (Figure 5-3 A, C, D and E) were higher than the pressure during the relevé and lower portions of motion. At M1PIP (Figure 5-3 B) the opposite occurred, pressure peaked during the relevé to retiré and during the lower, but the pressure was less while the participants were on full pointe.

Figure 5-3

Ensemble means (solid lines) and standard deviations (dashed lines) of each toe pad condition during balance in retiré recorded at (A) DHAL, (B) M1PIP, (C) M1MTP, (D) Do1MTP, and (E) L5MTP



The interpretations of the PCs as well as the percent variance explained for each sensor during balances in retiré are displayed in Appendix Table 9.3. Significant *PC-Score* comparisons for the balances in retiré can be seen in Table 5.3 and ANOVA results can be seen in Appendix Table 9.4. During the balances in retiré, all sensors except DHAL had statistically significant *PC1-scores* (medium to large effect sizes). *PC1-scores* represented an overall change in magnitude and shape (Figure 5-4). At M1MTP and Do1MTP the gel toe pad had significantly higher *PC1-scores* than the other conditions. This indicates that using the gel toe pad resulted in a higher pressure throughout the motion (Figure 5-3 C and D). L5MTP showed the custom toe pad had significantly lower *PC-scores* than the other conditions indicating this toe pad had the lowest pressure at L5MTP's location (Figure 5-3 E). Although a difference in means was detected at M1PIP, no significant pairwise comparisons were found; however, the gel and custom conditions were approaching significance (p=0.085) (Figure 5-3 E). M1MTP *PC2-scores* represented a difference operator (Figure 5-4 E-F) and had a small effect size. The custom toe pad had higher *PC2-scores* than the gel toe pad, indicating smaller pressures during the pliés and larger pressures during the balance in retire for the custom toe pad (Figure 5-3 C).

Table 5.3

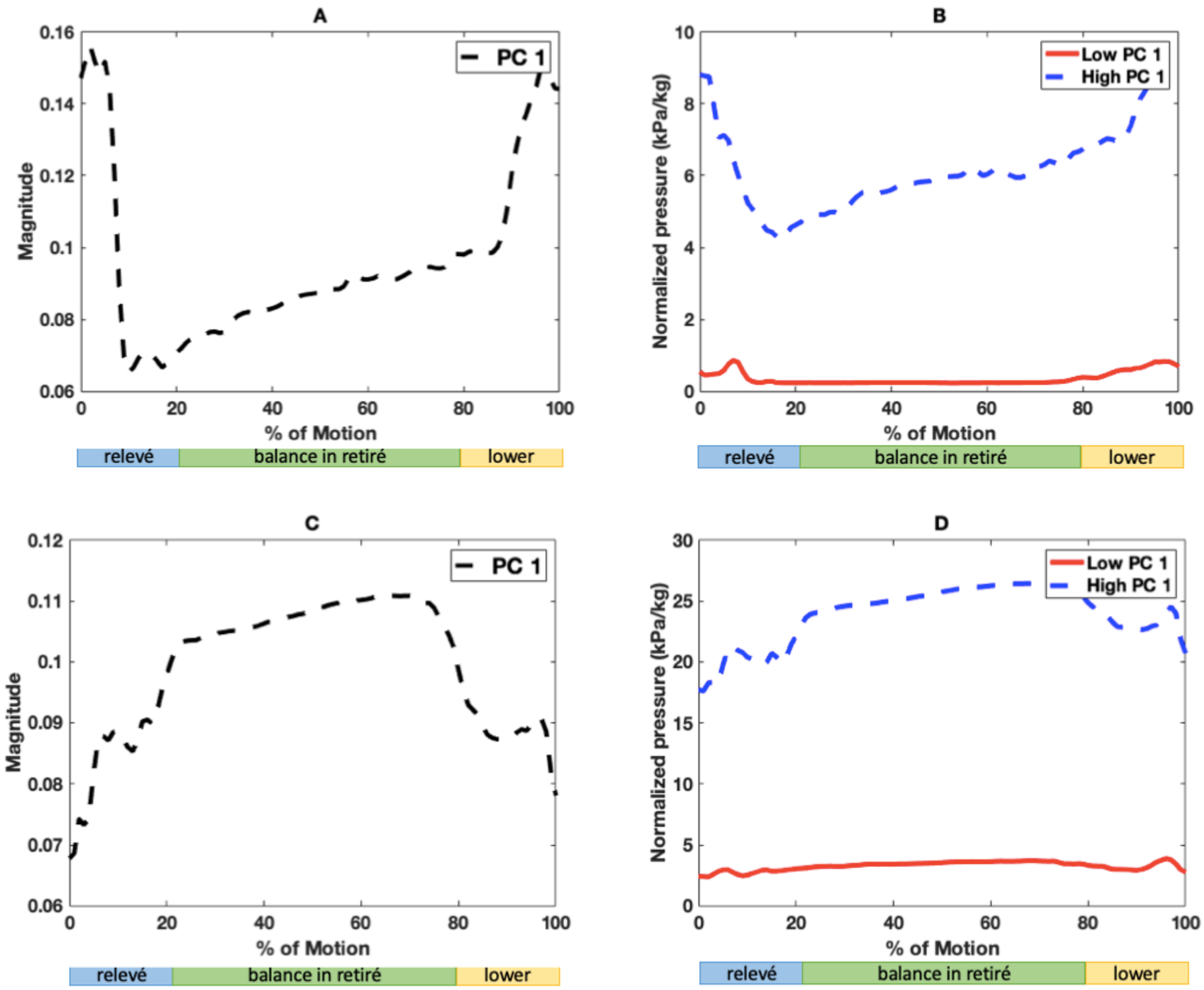
Pairwise comparison of significant PCs during balances in retiré

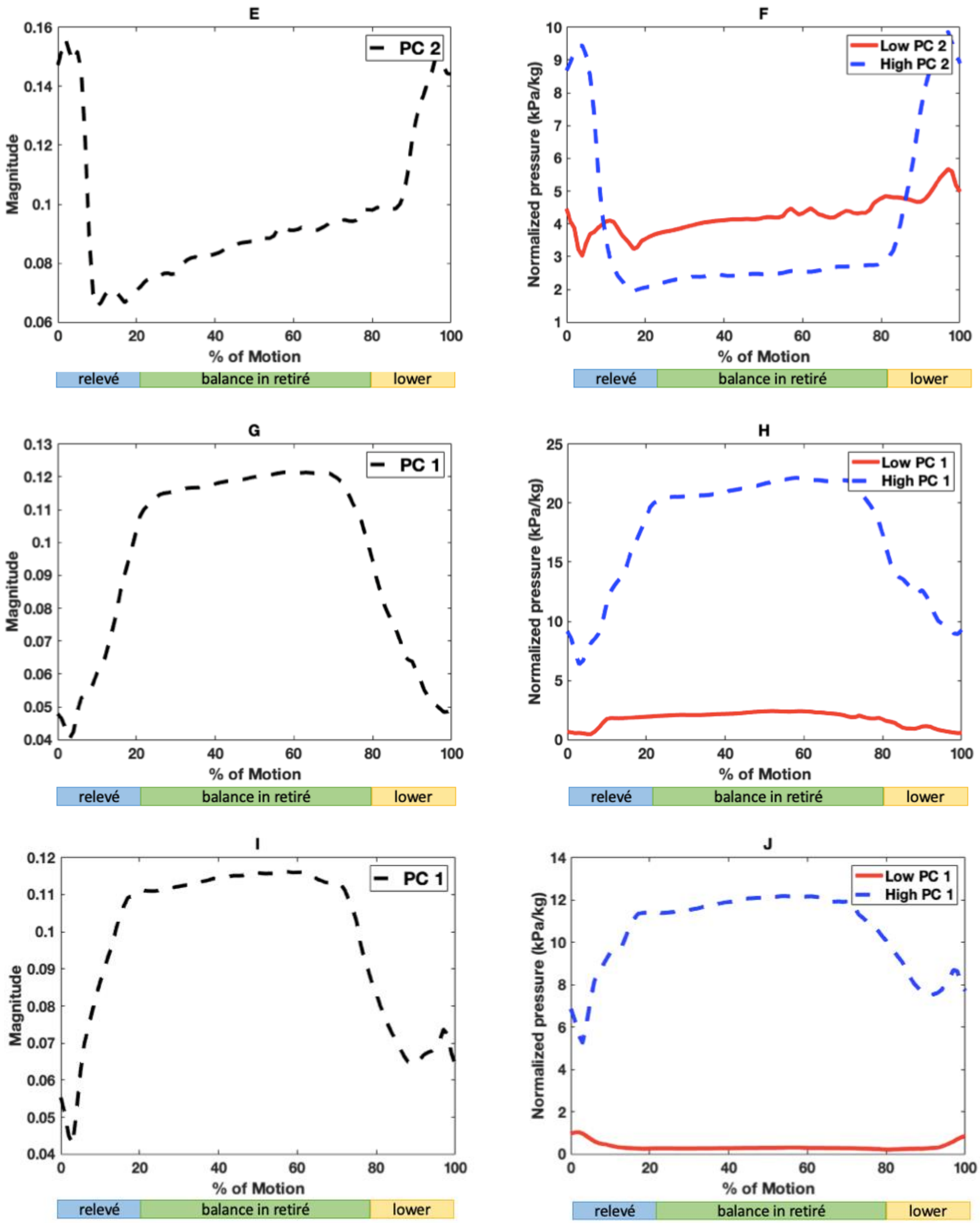
Sensor	PC		Gel vs. Custom Significance	Participant's Choice vs. Gel Significance	Custom vs. Participant's Choice Significance	Partial Eta Squared
2	1	Mean *PC-score* difference	1 302	-796	-506	0.131
		p	*p*=0.085	*p*=0.210	*p*=0.330	
3	1	Mean *PC-score* difference	4 844	-3 199	-1 644	0.322
		p	*p*<0.001*	*p*=0.005*	*p*=0.328	
	2	Mean *PC-score* difference	-535	220	315	0.104
		p	*p*=0.009*	*p*=0.815	*p*=0.659	
4	1	Mean *PC-score* difference	3 959	-3 729	-229	0.278
		p	*p*=0.001*	*p*=0.002*	*p*=1.00	
5	1	Mean *PC-score* difference	2 472	-938	-1 534	0.284
		p	*p*<0.001*	*p*=0.236	*p*=0.033*	

Note. Significant results are indicated with an asterisk. Bonferonni's correction was used for determining pairwise significance.

Figure 5-4

Significant principal components during balances in retiré at (A) M1PIP, (C and E) M1MTP, (G) Do1MTP, (I) L5MTP. To assist with interpretation, a subset of participants with high and low PC-Scores were plotted next to their corresponding PC. This was done at (B) M1PIP, (D) M1MTP, (F and H) Do1MTP, and (J) L5MTP



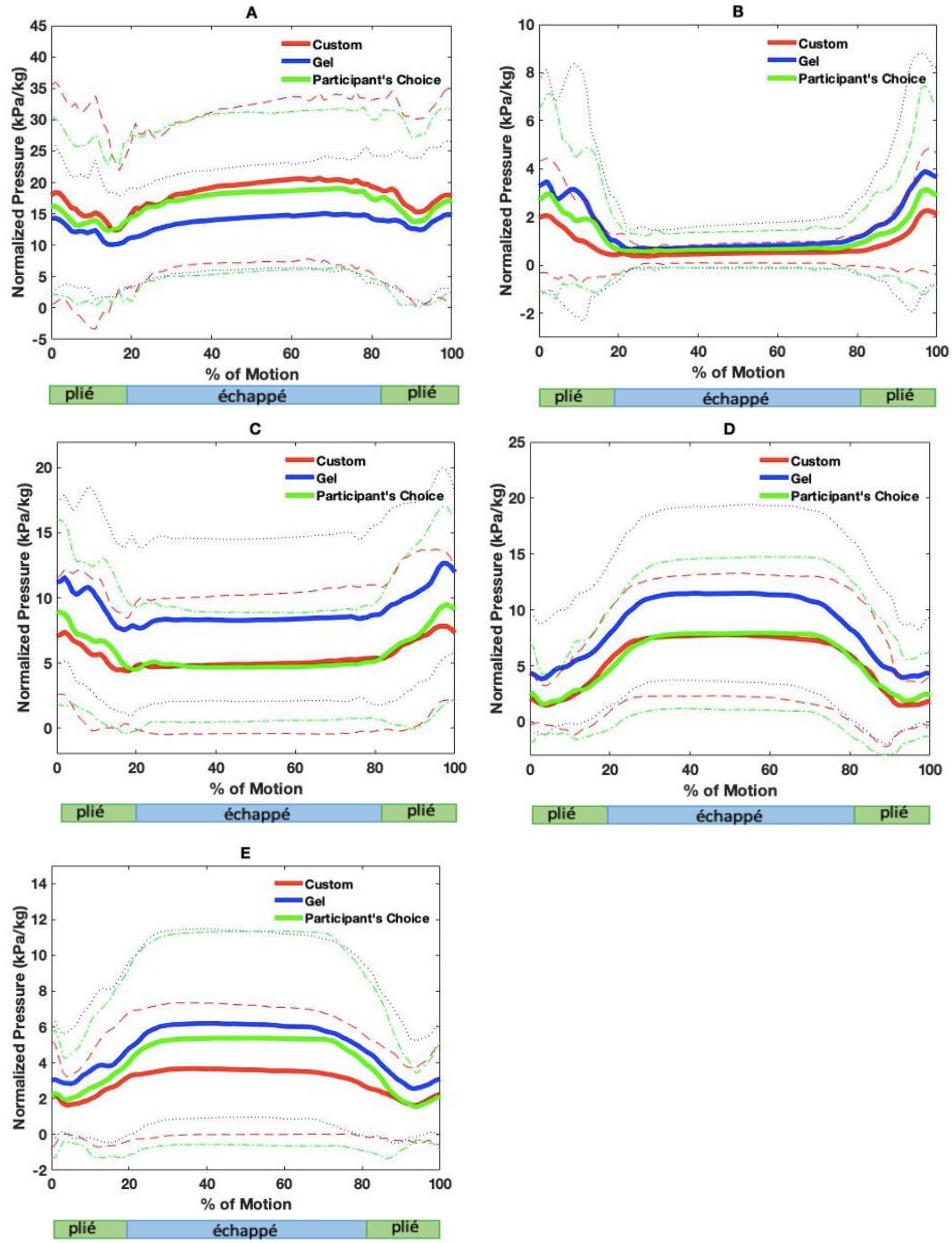

E
Magnitude
% of Motion
PC 2
relevé
balance in retiré
lower
F
Normalized pressure (kPa/kg)
% of Motion
Low PC 2
High PC 2
relevé
balance in retiré
lower
G
Magnitude
% of Motion
PC 1
relevé
balance in retiré
lower
H
Normalized pressure (kPa/kg)
% of Motion
Low PC 1
High PC 1
relevé
balance in retiré
lower
I
Magnitude
% of Motion
PC 1
relevé
balance in retiré
lower
J
Normalized pressure (kPa/kg)
% of Motion
Low PC 1
High PC 1
relevé
balance in retiré
lower

5.1.3 Échappés

The mean pressure waveforms (solid lines) and standard deviations (dotted lines) during the échappés are displayed in Figure 5-5. The pressure at DHAL, Do1MTP and L5MTP (Figure 5-5 A, D and E) was highest during the échappé motion, while the participant is springing on both feet into second position. The pressure at these locations during the pliés are lower. At M1PIP and M1MTP (Figure 5-5 B and C), the pressure peaked during the pliés and was lower during the échappé motion.

Figure 5-5

Ensemble means (solid lines) and standard deviations (dashed lines) of each toe pad condition during échappés recorded at (A) DHAL, (B) M1PIP, (C) M1MTP, (D) Do1MTP, and (E) L5MTP



The interpretations of the PCs as well as the percent variance explained for each sensor during échappés are displayed in Appendix Table 9.5. Significant *PC-score* comparisons for the échappés can be seen in Table 5.4 and the ANOVA results are displayed in Appendix Table 9.6. All the sensors showed statistically significant *PC1-scores* and all the *PC1-scores* represented an overall change in magnitude and shape (Figure 5-6). At DHAL, the gel toe pad had significantly lower *PC1-scores* than the other conditions, therefore throughout the entire échappé; use of the gel toe pad resulted in the lowest pressure with a medium effect size (Figure 5-5 A). At M1MTP and Do1MTP's locations, the gel toe pad had significantly higher *PC1-scores* than the other conditions and large effect sizes. Use of the gel toe pad resulted in the highest pressure throughout the motion (Figure 5-5 C and D). *PC1-scores* from M1PIP (medium effect size) and L5MTP (large effect size) were significantly lower in the custom compared to the gel toe pad demonstrating the custom toe pad had lower pressures (Figure 5-5 B and E). M1MTP *PC2-scores* indicated that custom toe pads had significantly higher PC-scores than the other conditions (small effect) (Figure 5-6 G-H). This indicates that the custom toe pad had larger changes in pressure, a smaller magnitude during the plié and a higher magnitude during the échappé (Figure 5-5 C).

Table 5.4

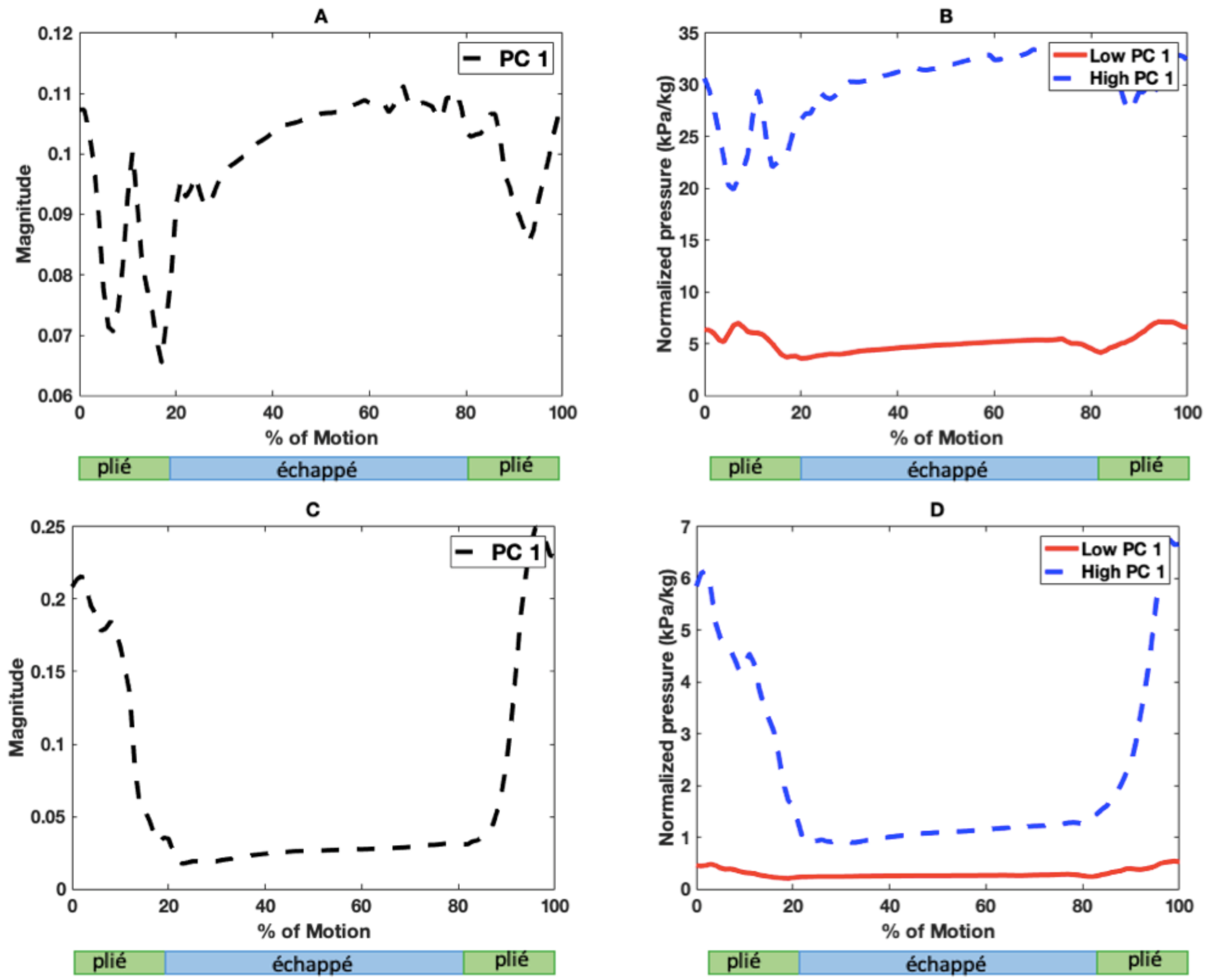
Pairwise comparison of significant PCs during échappés

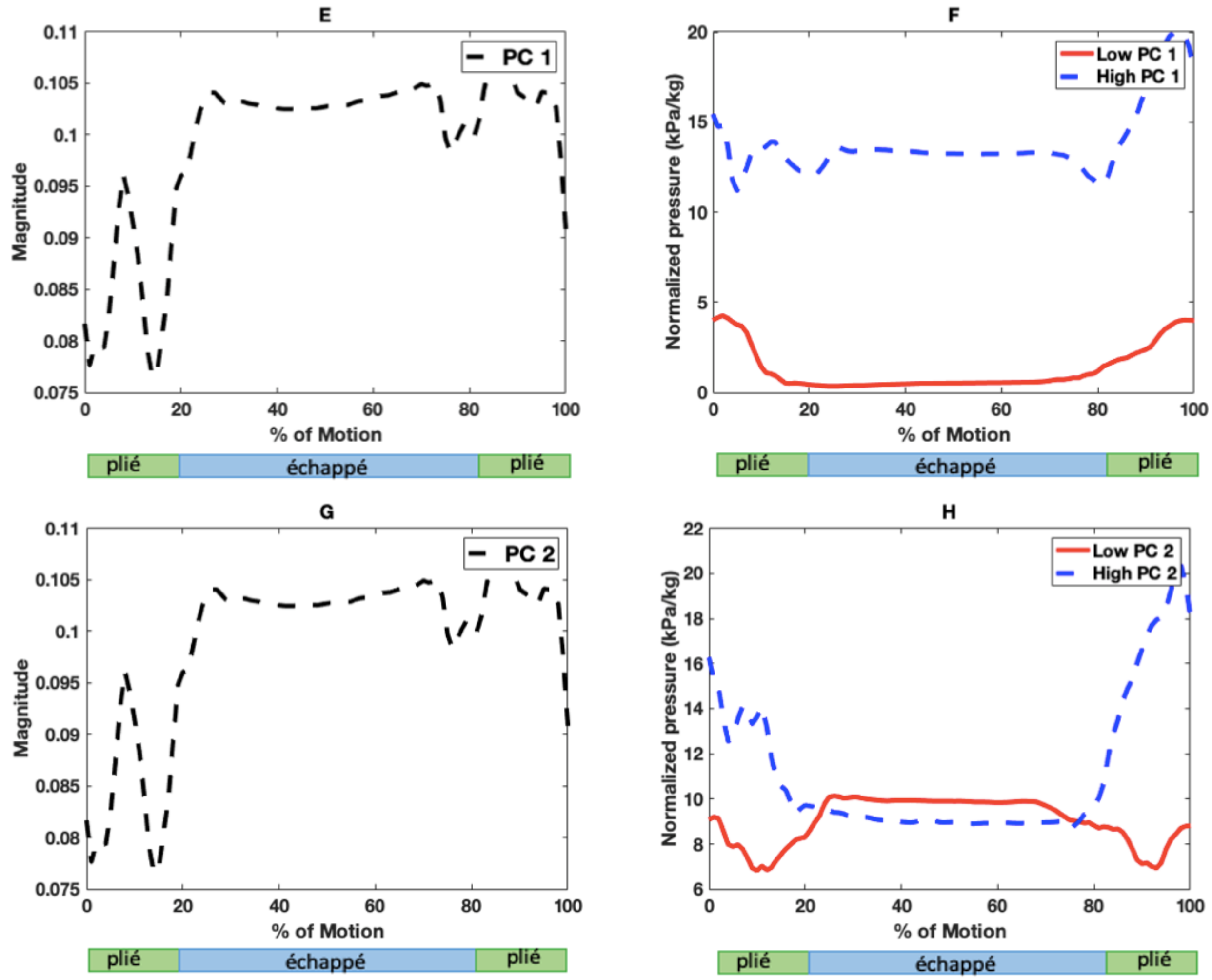
Sensor	PC		Gel vs. Custom Significance	Participant's Choice vs. Gel Significance	Custom vs. Participant's Choice Significance	Partial Eta Squared
1	1	Mean *PC-score* difference	-4 538	3 229	1 310	0.157
		p	*p*=0.022*	*p*=0.035*	*p*=1.00	
2	1	Mean *PC-score* difference	817	-388	-429	0.147
		p	*p*=0.047*	*p*=0.427	*p*=0.077	
3	1	Mean *PC-score* difference	3 585	-3 388	-198	0.307
		p	*p*<0.001*	*p*<0.001*	*p*=0.100	
	2	Mean difference	442	116	-558	0.119
		p	*p*=0.013*	*p*=1.00	*p*=0.025*	
4	1	Mean *PC-score* difference	3 608	-3 165	-443	0.301
		p	*p*=0.002*	*p*=0.004*	*p*=1.00	
5	1	Mean *PC-score* difference	2 040	-723	-1 317	0.226
		p	*p*<0.001*	*p*=0.525	*p*=0.076	

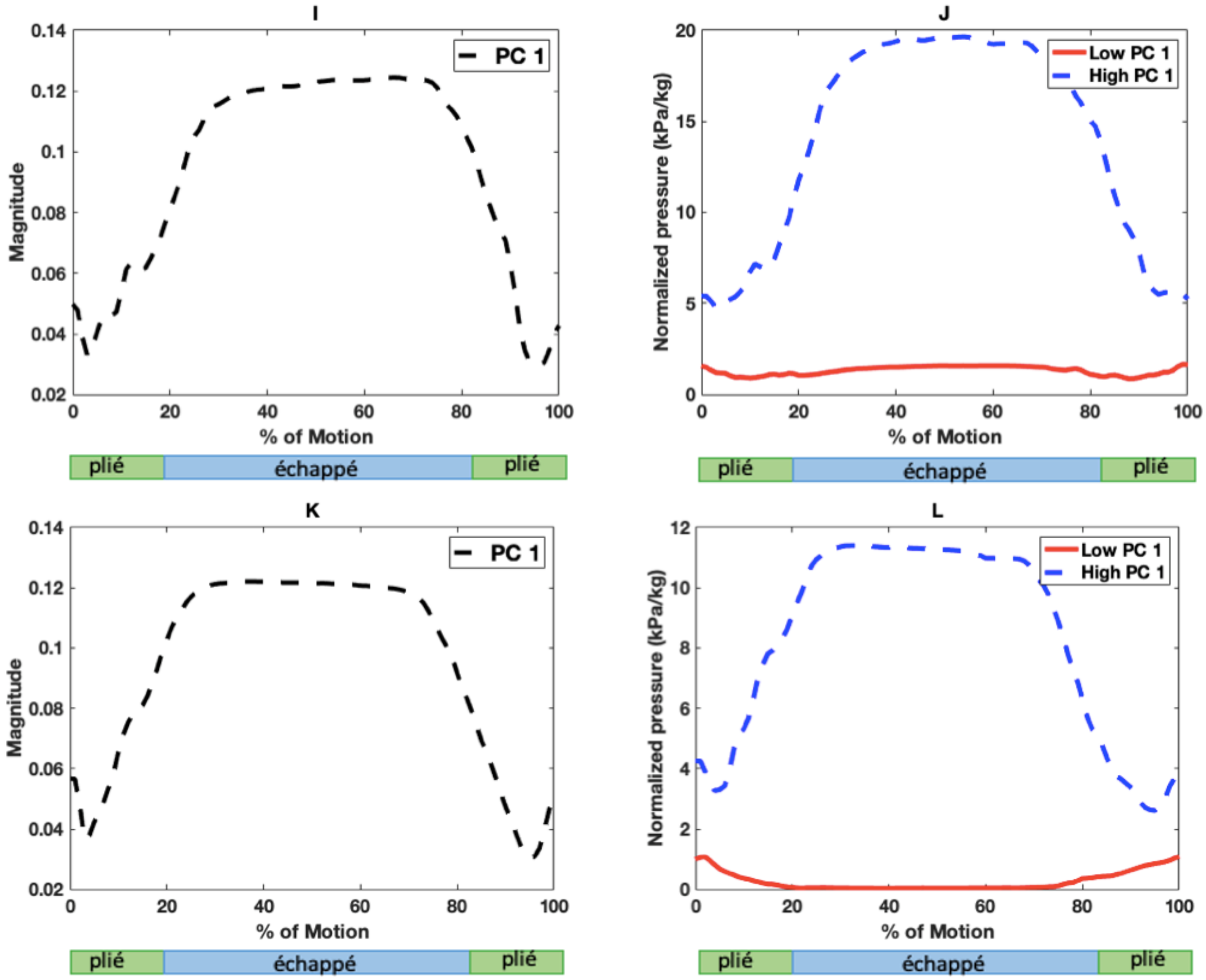
Note. Significant results are indicated with an asterisk. Bonferonni's correction was used for determining pairwise significance.

Figure 5-6

Significant principal components during échappés at (A) DHAL, (C) M1PIP, (E and G) M1MTP, (I) Do1MTP, (K) L5MTP. To assist with interpretation, a subset of participants with high and low PC-Scores were plotted next to their corresponding PC. This was done at (B) M1PIP, (D) M1MTP, (F and H) Do1MTP, and (J) L5MTP




E
PC 1
Magnitude
% of Motion
F
Low PC 1
High PC 1
Normalized pressure (kPa/kg)
% of Motion
G
PC 2
Magnitude
% of Motion
H
Low PC 2
High PC 2
Normalized pressure (kPa/kg)
% of Motion
plié
échappé
plié



5.1.4 Flat foot stance

Significant pairwise differences between toe pad conditions during the normal flat foot stance are displayed in Table 5.5 and are plotted in Figure 5-7. The ANOVA results are displayed in Appendix Table 9.7. All sensors except DHAL showed a significant difference and this comparison resulted in a medium effect size at M1PIP, Do1MTP, and L5MTP, and a large effect size at M1MTP. There were significant differences between the gel toe pad and the other conditions for all significant sensors. In all instances, the use of the gel toe pad resulted in higher pressures on the feet than the other toe pad conditions.

Table 5.5

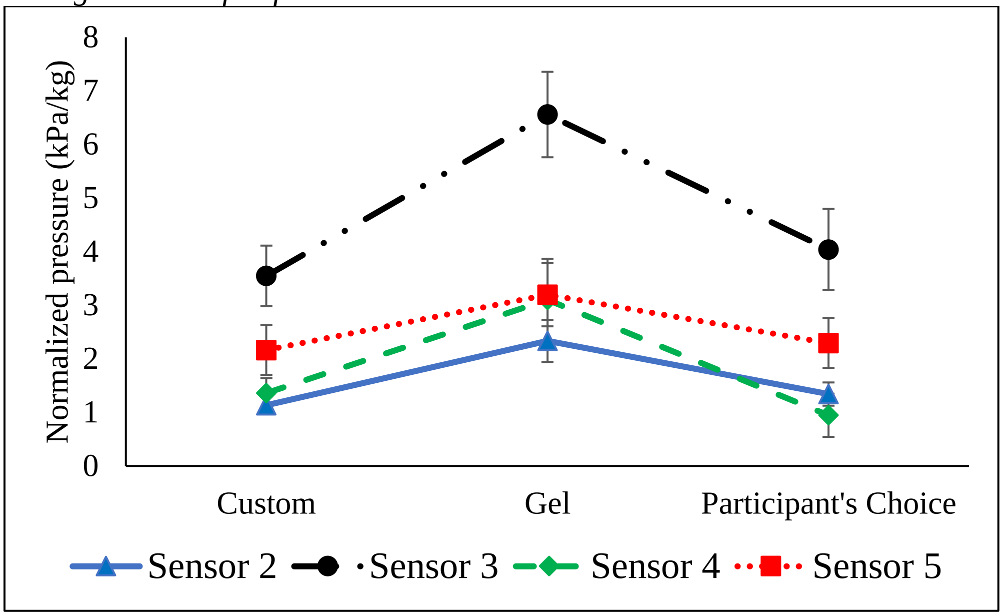
Pairwise comparison of significant average normalized pressures during flat foot stance

Sensor		Gel vs. Custom Significance	Gel vs. Participant's Choice Significance	Custom vs. Participant's Choice Significance	Partial Eta Squared
2	Mean difference (kPa/kg)	1.201	0.993	0.208	0.22
	p	*p*=0.014*	*p*=0.014*	*p*=0.98	
3	Mean difference (kPa/kg)	3.012	2.518	0.493	0.26
	p	*p*<0.001*	*p*=0.010*	*p*=1.00	
4	Mean difference (kPa/kg)	1.742	2.155	0.412	0.24
	p	*p*=0.026*	*p*=0.005*	*p*=0.665	
5	Mean difference (kPa/kg)	1.032	0.901	0.130	0.16
	p	*p*=0.020*	*p*=0.049*	*p*=1.00	

Note. Significant results are indicated with an asterisk. Bonferonni's correction was used for determining pairwise significance.

Figure 5-7

Mean pressure normalized to body weight across toe pad conditions at significant sensors during a normal flat foot stance



5.2 Secondary variables' effects on principal components

Some data sets were transformed with a Yeo-Johnson transform to meet the assumptions of a repeated measures factorial ANOVA for the secondary variable analysis. For rises and level of training tests these were M1PIP *PC1-scores*, M1PIP *PC2-scores*, and L5MTP *PC2-scores*. For rises and toe shape tests, transformed data sets were DHAL *PC2-scores* and L5MTP *PC1-scores*. For balances in retiré, M1PIP *PC1-scores* for level of training and L5MTP *PC1-scores* for toe shape were transformed. For échappés, M1PIP *PC1-scores*, M1PIP *PC2-scores* and M1MTP *PC2-scores* were transformed when tested with level of training. When échappés and toe shape were tested, L5MTP *PC1-scores* were transformed. Of the 74 repeated measures factorial ANOVAs completed for the secondary variable analyses, 11 data sets were transformed.

5.2.1 Rises

The results of the secondary variable analysis for both toe shape and level of training during rises are displayed in Appendix Table 9.8 and Appendix Table 9.9. When examining toe shape, there was a significant interaction between toe shape and toe pad condition at M1MTP

PC3-scores (*p*=0.013) (Figure 5-8 A), which represented a phase shift, meaning there was a difference in the timing of the onset of pressure (Figure 5-9 A and B). Further pairwise comparisons revealed no significant differences between toe shape groups within each toe pad condition. When examining level of training, a significant main effect was found for M1MTP *PC4-scores* during rises (Figure 5-8 B) which represented a phase shift (Figure 5-9 C and D). Recreational dancers had higher *PC4-scores*, indicating that they experienced the onset of pressure at this location at a slower rate than dancers training at an elite level (*p*=0.015; mean difference=464.64). A significant interaction between level of training and toe pad condition was detected for L5MTP *PC2-scores* (*p*=0.019) (Figure 5-8 C) which represented a difference operator, meaning there was a difference in the shape of the pressure waveforms (Figure 5-9 E and F). There were however no significant pairwise differences between training level groups in any toe pad condition.

Figure 5-8

(A) Significant interactions between toe length and toe pad condition's PC3-Scores at M1MTP, (B) main effects of training level on PC4-Scores at M1MTP, and (C) interactions between training level and toe pad condition's PC2-Scores for L5MTP during rises

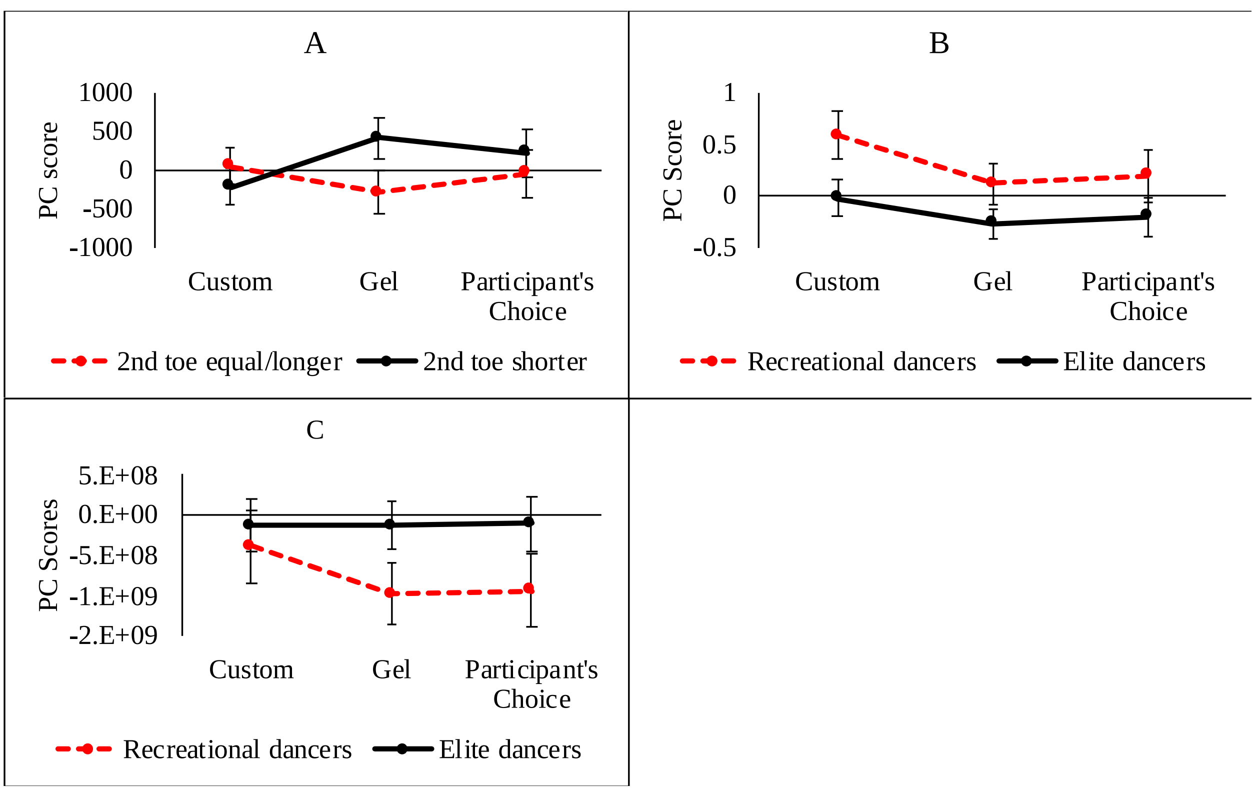
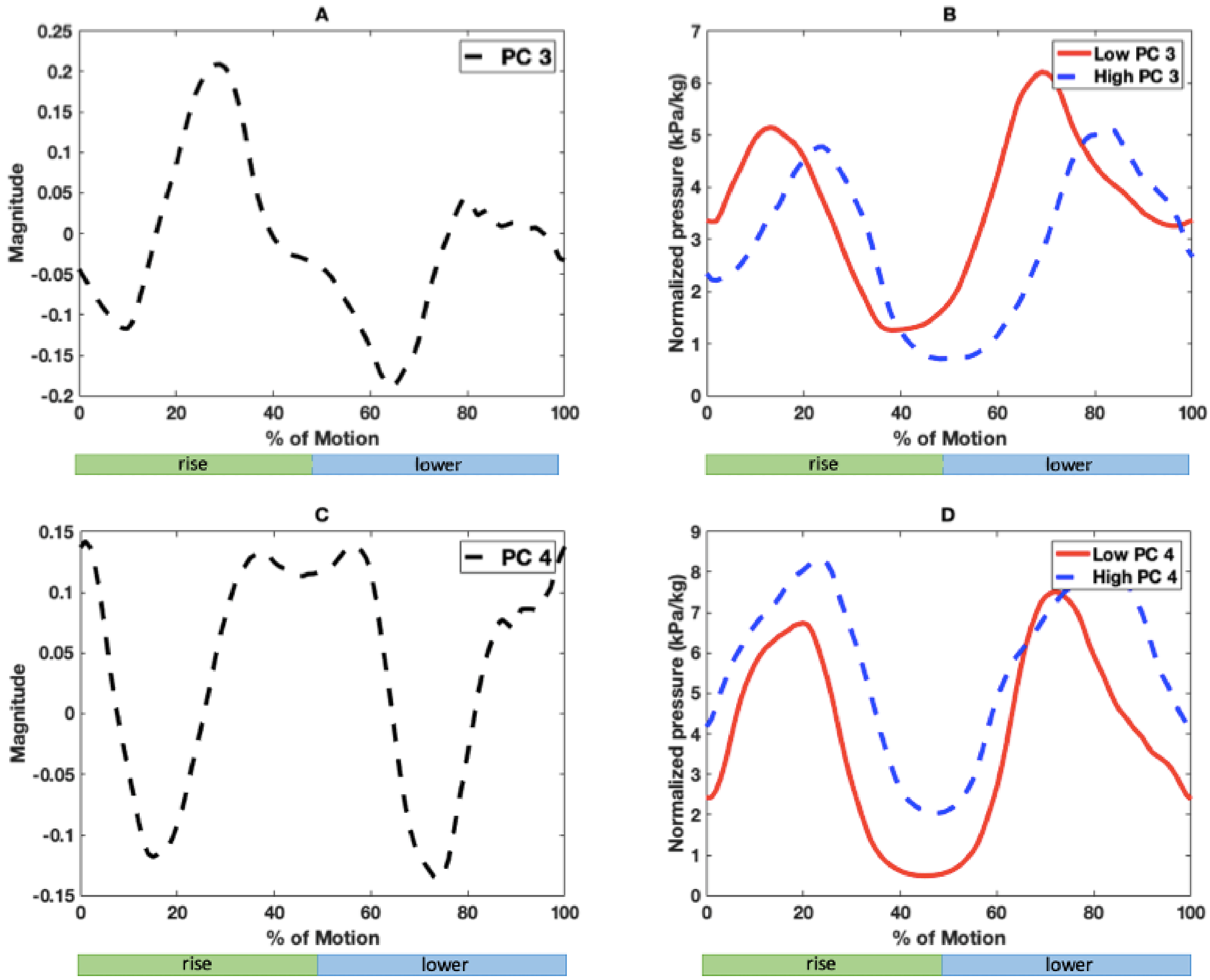
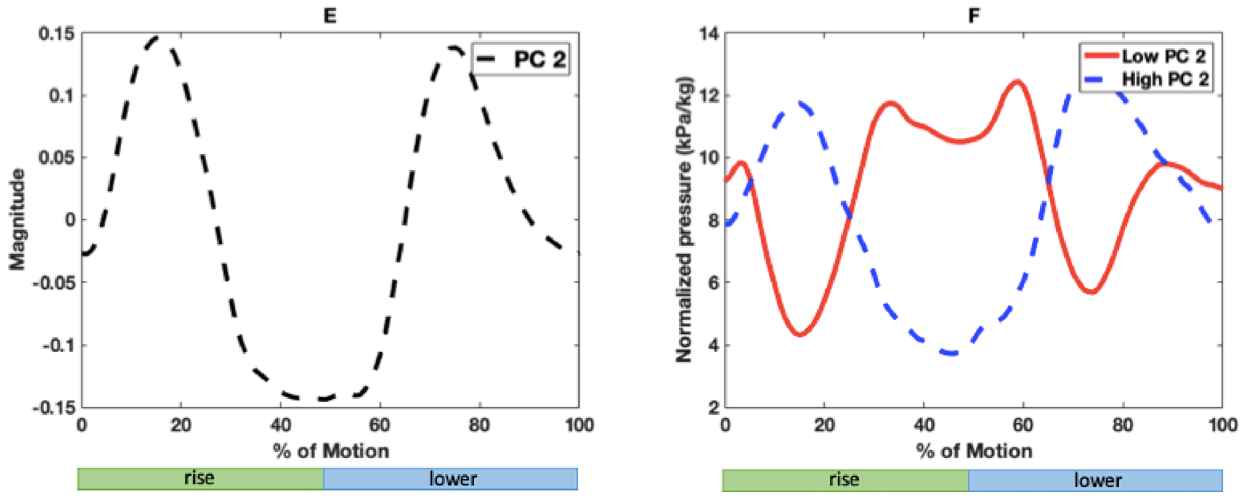


Figure 5-9

Significant principal component main effects and interactions during rises at (A and C) M1MTP and (E) L5MTP. To assist with interpretation, a subset of participants with high and low PC-Scores were plotted next to their corresponding PC. This was done at (B) M1PIP, (D) M1MTP, (F and H) Do1MTP, and (J) L5MTP



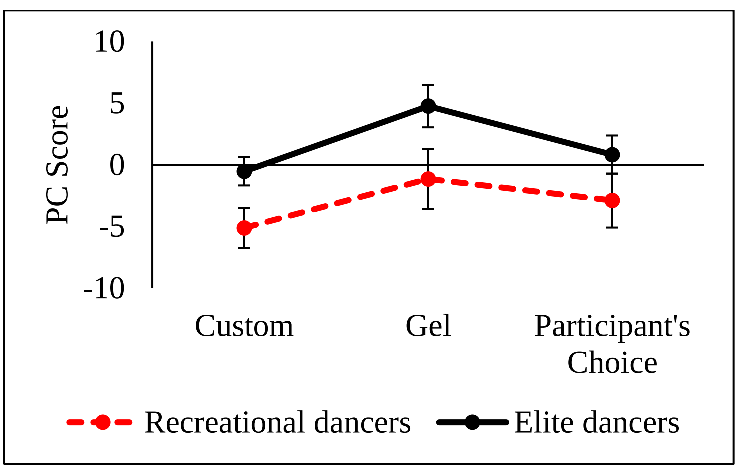


5.2.2 Balances in retire

The results of the secondary variable analysis for both toe shape and level of training during balances in retiré are displayed in Appendix Table 9.10 and Appendix Table 9.11. A significant main effect from level of training was detected for M1MTP's *PC1-scores* during the balances in retire (*p*=0.049; Figure 5-10). This PC represented an overall change in magnitude and shape (Figure 5-4 C). Participants who train at an elite level experienced higher pressure at M1MTP (higher *PC1-scores*) than participants who train at a recreational level (mean difference=4.74).

Figure 5-10

Main effects of level of training on M1MTP PC1-Scores across toe pad conditions during balances in retire



5.2.3 Échappés

The results of the secondary variable analysis for both toe shape and level of training during échappés are displayed in Appendix Table 9.12 and Appendix Table 9.13. A significant interaction between level of training and toe pad condition during échappés was detected (Figure 5-11). The interaction was found for M1PIP *PC2-Scores* (*p*=0.038) and represented a difference operator meaning there was a difference in overall shape (Figure 5-12). There were, however, no significant pairwise comparisons between training levels at each toe pad condition.

Figure 5-11

Interactions between level of training and toe pad condition on M1PIP PC2-Scores during échappés

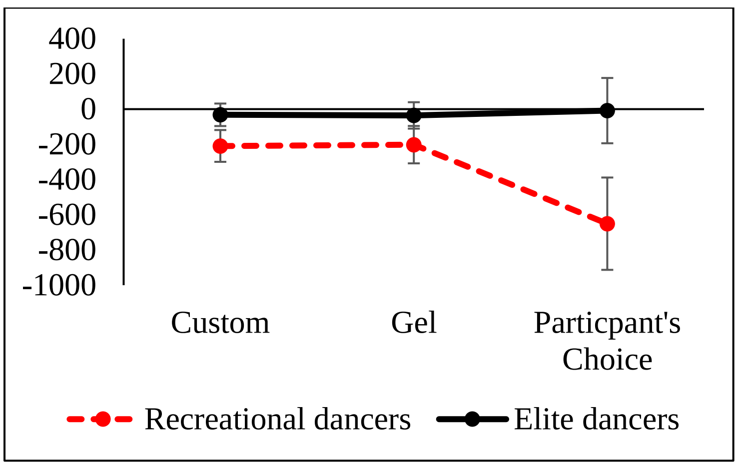
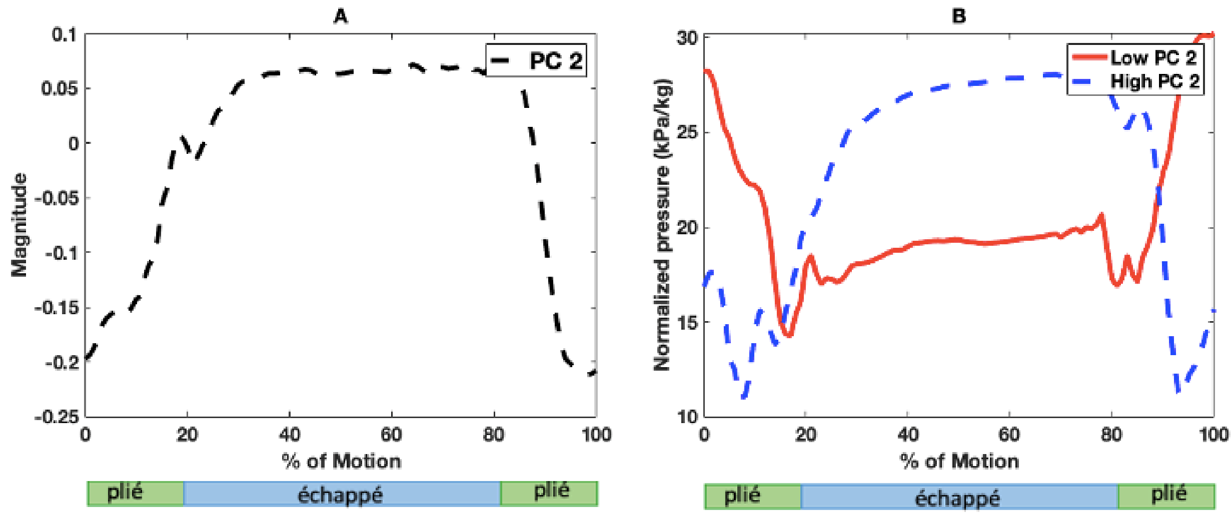


Figure 5-12

(A) Significant principal component interactions during échappés at M1PIP. (B) To assist with interpretation, a subset of participants with high and low PC-Scores were plotted next to their corresponding PC at M1PIP.



5.3 Friedman and Wilcoxon tests on survey data

The medians, ranges, and significance of each of the survey variables are displayed in Table 5.6. Many survey variables had significant differences between toe pad conditions with small and medium effect sizes. Significant pairwise differences were detected between the gel toe pad condition and the custom molded condition with the custom toe pad having a higher mean rank for overall comfort (p=0.002), overall control (p=0.030), overall stability (p=0.001), overall fit (p=0.002), overall performance (p=0.001), right comfort (p<0.001), left comfort (p<0.0021), right stability (p=0.020), left stability (p=0.005), right pressure (p<0.001), and left pressure (p<0.001). Significant pairwise differences also occurred between the gel and participant's choice conditions with the participant's choice condition having higher mean ranks for overall comfort (p=0.004) overall control (p=0.003), overall fit (p=0.030), overall performance (p=0.030), right stability (p=0.045), and left stability (p=0.030). Finally, there were significant pairwise differences between the custom and participant's choice conditions with the custom condition having a higher mean rank for overall stability (p=0.035), right comfort (p=0.010), left comfort (p=0.020), right pressure (p=0.002), and left pressure (p=0.010).

As displayed in Table 5.6, when dancing with the gel toe pad, participants perceived it to provide less comfort, less control, a poorer fit, lower stability, and a lower overall performance compared to the other toe pad conditions. Overall comfort had a medium effect size and the other variables all had small effect sizes. When dancing with the custom toe pad, participants perceived it to provide better stability, better comfort, and less pressure with small effect sizes.

Table 5.6

Median ratings, ranges, mean ranks, and significance of participant perception variables

	Gel		Custom		Participant's Choice		Friedman p	Kendall's W
	Median (range)	Mean rank	Median (range)	Mean rank	Median (range)	Mean rank		
Overall comfort	4 (4)	1.47	5 (3)	2.43	4 (4)	2.10	<0.001*	0.314
Overall control	4 (3)	1.59	4 (3)	2.12	5 (4)	2.29	0.003*	0.197
Overall stability	4 (3)	1.64	5 (3)	2.41	4 (4)	1.95	0.002*	0.216
Overall fit	4 (3)	1.64	5 (4)	2.34	4 (3)	2.02	0.005*	0.186
Overall articulation	4 (3)	1.72	4 (3)	2.16	4 (3)	2.12	0.08	N/A
Overall performance	4 (4)	1.60	5 (2)	2.38	4 (4)	2.02	0.001*	0.233
Right comfort (cm)	6.2 (8.4)	1.43	7.7 (7.7)	2.66	6.6 (9.5)	1.91	<0.001*	0.384
Left comfort (cm)	5.3 (7.1)	1.57	7.9 (6.0)	2.47	6.5 (8.3)	1.97	0.002*	0.209
Right control (cm)	6.9 (7.8)	1.74	7.5 (8.8)	2.00	7.7 (9.6)	2.26	0.13	N/A
Left control (cm)	7.0 (8.0)	1.74	7.1 (8.8)	2.05	7.3 (9.2)	2.21	0.17	N/A
Right stability (cm)	6.8 (7.4)	1.60	7.3 (8.3)	2.31	7.4 (9.7)	2.09	0.02*	0.135
Left stability (cm)	6.7 (7.6)	1.62	7.5 (7.6)	2.40	7.4 (8.6)	1.98	0.01*	0.155
Right pressure (cm)	4.9 (7.9)	1.53	7.7 (7.3)	2.55	5.1 (9.6)	1.91	<0.001*	0.267
Left pressure (cm)	4.9 (7.3)	1.52	7.5 (7.6)	2.48	5.4 (9.0)	2.00	0.001*	0.233

Note. Significant results are indicated with an asterisk.

6 Discussion

6.1 Summary of Results

This study is the first to directly compare the pressure distribution that fit accessories provide to the forefoot in pointe shoes as well as dancer's perceptions of using different toe pad designs. Throughout double legged rises en pointe, and one legged releves to retire at the barre, wherever a significant difference in pressure magnitude occurred between toe padding conditions, one of two scenarios always occurred. The custom molded toe pad always provided the lowest pressure, or the gel toe pad always provided the highest pressure. During the échappés to second position, this was also the case, except at the distal end of the hallux. This location experienced the lowest pressure with the gel toe pad during échappés, not the custom molded toe pad. The participant's choice padding condition always acted similarly to either the gel or custom toe pad, it was never significantly different from both the custom and gel conditions at the same time which may be due to the high variability within the participant's choice condition. Dancers perceived the custom toe pad to have higher ratings or the gel toe pad to have lower ratings for comfort, control, stability, fit and overall performance although these perceptions generally had small effect sizes.

6.2 Implications of results

Due to the custom toe pad resulting in lower pressures than the other conditions or the gel resulting in higher pressures than the other conditions, dancers may benefit from using a toe pad that facilitates good foot and shoe contact area. This may be achieved with a custom molded toe pad or by strategically placing other fit accessories like tape and lamb's wool in areas of negative space within the shoe to create a customized fit. Concentrated areas of high pressure on the soft tissue and non-load bearing bones of the forefoot can contribute to issues such as bruised and thickened toenails, hammer toes, hallux rigidus, hallux valgus, Morton's neuroma, corns, dorsal exostosis, sesamoiditis and extensor tendinitis (Barringer & Schlesinger, 2021, p. 371-383). The use of custom molded toe pads or a fit accessory that provides a more even pressure distribution may help reduce these occurrences. The use of custom molded toe pads or another fit accessory that provides good shoe and foot contact area may also decrease dancer's perceptions of pressure and increase feelings of comfort and stability. This may allow dancers to better concentrate on their training, reduce injuries, reduce missed training time, and allow more dancers to enjoy pointe work. Dancers of all levels and with all toe shapes may benefit from these recommendations.

6.3 Rises

Rises are a slow movement that required participants to utilise their full foot strength and flexibility to produce a controlled and precise movement. During this movement, the custom molded toe pad resulted in significantly lower pressures at the medial side of the 1^{st} PIP joint (M1PIP *PC1-scores*), and the lateral side of the 5^{th} MTP joint (L5MTP *PC1-scores*) compared to the other conditions. The gel toe pad resulted in significantly higher pressures at the medial and dorsal sides of the 1^{st} MTP joint (Sensors 3 and 4 *PC1-scores*). There is no existing research comparing the pressure distribution during rises across various toe pad types and thus comparisons to other studies cannot be made. These results did align with the hypothesis. The custom toe pad had larger foot and shoe contact area and resulted in lower pressure distribution. In contrast, the gel toe pad had less foot and shoe contact area resulting in higher pressures. The custom toe pad also demonstrated a significantly higher overall change in pressure at the dorsal side of the 1^{st} MTP joint (Do1MTP *PC5-scores*) than the participant's choice condition. This may be due to the custom toe pad having a lower pressure during a normal flat foot stance compared to the participant's choice toe pad at this location. Although the difference during the flat foot stance was not significant, it may help explain the larger pressure range recorded with the custom molded toe pad compared to the participant's choice.

6.4 Balances in retiré

Dancers relevéd to retiré position, took their hands off the barre and balanced for a moment before returning to a plié. This was a quick motion on one leg. Throughout this motion, the custom molded toe pad provided significantly lower pressure to the lateral side of the 5^{th} MTP joint (L5MTP *PC1-scores*) compared to the other toe pad conditions. Use of the gel toe pad during this movement resulted in higher pressure on both the medial and dorsal sides of the 1^{st} MTP joint (Sensors 3 and 4 *PC1-scores*). There is no existing research comparing the pressure distribution during balances in retiré across various toe pad types therefore comparisons to other studies cannot be made. However, these results for the balances in retiré also aligned with the hypothesis. These findings are again likely due to the custom condition increasing contact area between the shoe and foot. A difference in overall pressure was also detected between the gel and custom conditions at the medial side of the 1st MTP joint (M1MTP *PC2-scores*). The custom condition had a larger pressure range, with a smaller magnitude during the pliés and larger magnitude during the balance. The custom toe pad may have had a larger pressure range at M1MTP because it had a lower baseline pressure during the normal flat foot stance. Its overall pressure range was larger than the gel toe pad despite it having a smaller total magnitude than the gel toe pad at this location.

6.5 Échappés

An échappé to second position is a quick spring onto two feet. This step generates higher force on the feet than the rises due to the higher acceleration. The use of the custom molded toe pad resulted in significantly lower pressures at the medial side of the 1st PIP joint (M1PIP *PC1-scores*) and the lateral side of the 5th MTP joint (L5MTP *PC1-scores*) compared to the gel toe pad condition during this step. The use of the gel toe pad resulted in significantly higher pressures at the dorsal and medial sides of the 1st MTP joint (Sensors 3 and 4 *PC1-scores*). These results were very similar to those found for the rises and balances in retiré, however, a result unique to the échappés was also detected. With the use of the gel toe pad, the pressure was significantly decreased at the distal end of the hallux (DHAL *PC1-scores*) compared to the other toe pad conditions. This was contrary to what was hypothesized but the result may be due to the gel toe pad providing a thick barrier between the foot and shoe and thus dampening and absorbing the force at this location. The custom toe pad would provide a much thinner amount of material at this location and therefore may not offer the same amount of dampening at this location as the gel toe pad. Additional testing with pressure sensors on the end of the other toes should be investigated in future studies. There was also a statistically significant difference between the total range of pressure for the custom toe pad and the other conditions at the medial side of the 1st MTP joint (M1MTP *PC2-scores*). The custom toe pad again had a larger pressure range which may be due to its baseline pressure reading being significantly lower than the gel toe pad, resulting in a larger total pressure range despite maintaining a lower overall magnitude.

6.6 Level of training

A few differences between training groups were found during the ballet steps. During rises, recreational dancers consistently experienced a delay in the onset of pressure at the medial side of the 1st MTP joint (M1MTP *PC4-scores*), no matter the toe pad condition, compared to the dancers training at an elite level. During the balance in retiré, dancers that trained at an elite level experienced significantly higher pressures than those training at a recreational level, regardless of toe pad type on the medial side of the 1st MTP joint (M1MTP *PC1-scores*). No other study considers a dancer's level of training when comparing pressure distribution on the forefoot in various toe pad types. The differences detected may be due to small changes in foot position that are a result of differing control, articulation, foot strength or foot flexibility as these factors are greatly impacted by a dancer's level of training. Additionally, elite dancers may have an increased number of calluses, corns or bunions effecting their 1st MTP joint compared to recreational dancers. This may change the profile of the foot and impact the way the foot experiences pressure at this location. The phase shift PCs may also be due to differences in the pace at which dancers complete the steps. Overall, there were minimal differences between training groups. This may be because differences are not significant, or the study was not sufficiently powered for this secondary analysis.

6.7 Toe shape

It was found that toe shape and toe pad condition impacted the timing of the onset of pressure at the medial side of the 1st MTP joint (M1MTP *PC3-scores*) during rises although pairwise comparisons did not show any significant pairings within toe pad conditions. A previous study found no relationship between pressure on the end of the first toe and toe shape during a stand en pointe with no toe padding, (Teitz et al. 1985). No significant differences between toe shape and pressure magnitude were identified during dynamic ballet steps in any padding condition either. The same study also found that padding a short second toe more evenly distributed the pressure across the first two toes (Teitz et al. 1985). The custom molded toe pad theoretically adds additional padding to a short second toe; however, no significant difference was detected between toe pad conditions at the end of the first toe during rises, regardless of participant toe shape. The lack of this finding may be due to the difference in task (static stand versus dynamic steps) or differences in the fit accessories utilised. This study may have also been insufficiently powered to detect significant differences across toe shape groups.

6.8 Dancer's perceptions of fit accessories

There was a significant difference in dancer's ratings of overall comfort and overall fit between the gel toe pads and the other conditions, with the gel toe pads being rated lower. When broken down between the right and the left, dancers rated the custom toe pad to be significantly more comfortable and result in less pressure points than the other conditions. This may be due to the custom toe padding having more foot and shoe contact area which causes a more even pressure distribution. This may be perceived by the dancer as increased comfort, better fit and fewer pressure points. The findings support this hypothesis although the differences were found to have mostly small effect sizes. The custom toe pad has already been found to reduce dancer's perceptions of discomfort when standing en pointe (Salzano et al., 2019), and this finding was confirmed in dynamic movements as well. Previous study also found that an orthotic that redistributed the plantar pressure more evenly across the foot in a soft technique shoe was rated more comfortable by the dancer (Miller et al, 1990). These results translate to pointe shoes as the toe pad with the most even pressure distribution and largest contact surface area, the custom toe pad, had the highest ratings of comfort on the left and right sides.

Dancers perceived the gel toe pad to provide significantly less overall control than the other conditions and perceived the custom toe pad to provide significantly more overall stability than the other conditions. These results may be due to an increase in proprioceptive feedback due to the increase in contact surface area with the custom toe pad. This may be perceived by the dancers as increased control, stability, and articulation of the foot's fine movements. There was no difference however in the shoe's ability to articulate the foot's movements and the effect size for all these variables were found to be small. The perceptions of having lower stability and overall control in the gel toe pad may be contributed to an excess of cushioning material in certain areas as this can dampen proprioceptive signals. This is a known phenomenon in the context of running shoes with excess cushioning (Squadrone & Gallozzi, 2011).

6.9 Recommendations for future study

There are several improvements and future directions that can be taken with the study of pointe shoe toe padding. Recording the pressure on the distal end of all the toes would greatly improve the understanding of results. Additionally, placing sensors on other joints of the forefoot such as the dorsal side of the 1^{st} PIP joint and the other MTP joints would also help make clear the ways in which the foot interacts with the pointe shoe. A longitudinal study would provide insight into how toe padding impacts dancer's foot health over a period of consistent use and if toe padding has an impact on injury rates. Further investigation into how toe padding may impact other kinetic and kinematic variables may also be beneficial. Toe padding's impact on forefoot joint alignment, joint forces and joint moments should also be further investigated to understand toe padding's potential impact on injury.

7 Limitations

This study had several limitations. The first is the variability present within different models of pointe shoes as participants wore their own shoes. Although a single model of pointe shoe could be used across all participants for consistency, one shoe model would not be well suited for all participants. There was also variation within the participant’s choice condition, as dancer’s existing toe padding were all different. The pressure sensors were too large to consistently place them on the distal end of participant’s toes so these measurements could not be captured accurately. The pressure sensor and their wires contributed to additional mass inside of the shoe that may influence how the foot and shoe interact. There may also be inconsistencies in the exact placement of the sensors due to differing geometry of participant’s feet. Additionally, the participants were familiar with the participant’s choice condition but not the custom and gel conditions and pressure may have been impacted as they became more familiar with these conditions. User’s perceptions of the toe pads may have been impacted by this as well. Finally, the survey gathering participant’s perception scores was created for this study and its reliability and validity were not tested.

8 Conclusions

Throughout the study there were two consistent results with a single exception. The use of gel toe pads resulted in the highest pressure on the forefoot, and the use of custom toe pads resulted in the lowest pressure on the forefoot during rises, relevés and balances in retirés and échappés. The exception to these findings was that at the end of the hallux during échappés the gel toe pad resulted in the lowest pressure. It is recommended that if dancers usually use a generic gel toe pad, they may consider the use of a custom molded toe pad, or another accessory that provides more foot and shoe contact area than a generic gel toe pad. Custom fit accessories may also provide dancers with feelings of increased stability, increased comfort, and lower pressure, allowing them to feel more confident dancing en pointe. Using fit accessories that provide a more even pressure distribution may help mitigate painful surface injuries and decrease overuse injuries, thereby reducing time spent recovering and allowing more dancers to enjoy pointe work. Dancers of all training levels and all toe shapes may benefit from using a fit accessory that provides a more even pressure distribution than a gel toe pad.

9 Appendices

Appendix Figure 9-1

Ethics Certificate

McGill

Research Ethics Board Office
James Administration Bldg.
845 Sherbrooke Street West. Rm 325
Montreal, QC H3A 0G4

Tel: (514) 398-6831

Website: www.mcgill.ca/research/research/compliance/human/

Research Ethics Board 3
Ethics Approval Certificate

REB File #: 22-08-007

Project Title: The effects of pointe shoe toe padding on ballet dancing

Principal Investigator: Kristin Higgins

Department: Kinesiology and Physical Education

Status: Master's Student

Supervisor: Professor Shawn Robbins

Approval Period: September 13, 2022 – September 12, 2023

The REB-3 reviewed and approved this project by delegated review in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement: Ethical Conduct For Research Involving Humans.

Lynda McNeil
Associate Director, Research Ethics

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* Approval is granted only for the research and purposes described.
* The PI must inform the REB if there is a termination or interruption of their affiliation with the University.
* An **Amendment-Legacy** form must be used to submit any proposed modifications to the approved research. Modifications to the approved research must be reviewed and approved by the REB before they can be implemented.
* Changes to funding or adding new funding to a previously unfunded study must be submitted as an Amendment.
* A **Continuing Review** form must be submitted before the above expiry date. Research cannot be conducted without a current ethics approval. Submit 2-3 weeks ahead of the expiry date.
A total of 5 renewals are permitted after which time a new application will need to be submitted.
* A **Termination** form must be submitted to inform the REB when a project has been completed or terminated.
* A **Reportable New Information** form must be submitted if any unanticipated issues that may increase the risk level to participants or that may have other ethical implications or to report any protocol deviations that did not receive prior REB approval.
* The REB must be promptly notified of any new information that may affect the welfare or consent of participants.
* The REB must be notified of any suspension or cancellation imposed by a funding agency or regulatory body that is related to this study.
* The REB must be notified of any findings that may have ethical implications or may affect the decision of the REB.

Appendix Figure 9-2

Consent form

The effects of pointe shoe toe padding on dancing ballet

Researchers:

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Sponsor(s): *PerfectFit Pointe*

Purpose of the Study:

The purpose of the study is to record the amount of pressure on your feet, and your joint's motion and forces when dancing on pointe with different types of toe pads. As you know, dancers often put different materials such as lamb's wool, gel pads, toe spacers, and even tissue in their shoes to create a better fit and relieve discomfort when they dance. Even though dancers have been using pointe shoes for a long time, there is not a clear understanding of how toe pads impact the way dancers use their shoes.

To understand what affects toe pads have on ballet dancing, we will use a camera system, force plates, pressure sensors, and surveys. The camera system will record the movement of your body and your joint angles. The force plates will be used to record the force your body exerts on the ground. Using these pieces of information, we will study your joint alignment and calculate the forces at your joints. The pressure sensors are thin and flexible and they will be used to measure the pressure on your feet created by your pointe shoes. We will use this to understand the way the pressure on your feet changes when you dance with different toe pads. We will also use surveys so you can tell us how you felt dancing with each type of toe pad. With these pieces of information, we hope that we can figure out the impact that toe padding has on dancing in pointe shoes. This will help dancers make decisions that are best for their foot health and their overall health.

Study Procedures:

You will arrive at McGill's Biomechanics and Performance Analysis Lab (475 Pine Ave W, Montreal) and will complete several ballet steps in your pointe shoes with a few toe padding conditions: gel toe pads, custom molded toe pads, and whatever materials (if any) you usually put in your shoes. You will also complete tendus and relevés with no toe pads.

The entire testing session will be about 3 hours long. You must bring a pair of pointe shoes that you are comfortable in. The shoes should already be broken in, but not worn out. If you feel comfortable wearing them during an entire ballet class, they will be appropriate. You will be asked to wear tight fitting athletic clothing that lets you move easily and does not cover your legs (such as compression/biker shorts). We will measure your height and weight and take other measurements such as foot length and foot width. You will fill out a questionnaire that will ask you basic information about your ballet training and your pointe shoes.

A set of thin, flexible pressure sensors that will measure the contact pressure between your feet and your pointe shoes will be taped to your feet with medical tape. The sensors will be wired into a computer that will record the pressure data. You will complete the following ballet steps in a random order with each type of toe pad:

- Relevés
- Échappés
- Balances in passé

We will also use a motion capture camera system combined with force plates. This will record your body's motion. Small reflective markers will be fixed to your body with medical tape. You will dance on the force plates, in each shoe padding condition and the system will record your motion and send it to the computer. The ballet steps you will complete are listed below and you will be asked to perform them in a random order.

- Tendus
- Relevés
- Échappés
- Balances/step into first arabesque

After you dance with each type of toe pad, you will be asked to complete a short questionnaire regarding your perceived pressure, comfort, control, and stability.

Voluntary Participation:

Your participation in this study is voluntary, and you may quit the study at any time, for any reason. If you choose to quit during or right after the study, any data collected up until that point will be destroyed and not used, unless you agree otherwise. Once the master list that identifies you to your data is destroyed (once data has been de-identified), your data cannot be removed. Data will be de-identified February 28, 2023 after this date, it will not be possible to remove your data from the study. All de-identified data will be kept for a period of 7 years after first publication.

Potential Risks: There are no likely risks to your health. Risk of injury is no greater than what you would experience during your regular ballet training. You may feel slight discomfort when dancing in a padding condition you are not used to, it may feel like being fit for a new pair of pointe shoes. The reflective markers will be fixed to your body with medical tape, this tape may cause mild irritation, if you have a known allergy to adhesives (such as band-aids) you will not be allowed to participate.

Potential Benefits:

From this research, we hope to better understand how dancers use their pointe shoes and how toe padding impacts dancing by finding:

○ Dancer's views on their foot comfort and control
○ The alignment of dancer's joints
○ The amount of pressure on dancer's feet created from their pointe shoes ○ The amount of force at dancer's joints

We also hope to contribute to ballet health and safety research by helping dancers, instructors, pointe shoe fitters, dance science/medicine professionals and physiotherapists understand how padding impacts dance and the best padding options for dancer's foot health and overall health.

Compensation:

You may keep the custom molded pointe shoe inserts you are given for use in this study, these have a retail value of $48 USD (about $62 CAD). If you are interested in the results of this study, you can add your email address, and we can send you a summary of the research outcomes.

I would like a summary of the research outcomes to be sent to me at the end of the study. Yes: ___ No:___

If yes, please provide your email: ___________________________

Confidentiality:

All your personal information (name, age, height, weight) collected during the study will be password protected to keep your confidentiality. Your data will be saved with the use of an identification code (consisting of your participant number and the date of the experiment). A master list identifying each participant to their code will be kept locked in a filing cabinet in the lab and will be destroyed after the data has been analyzed. This will de-identify all data. Data will be stored on a lab computer and will be kept confidential by the principal investigator, faculty supervisor/co-supervisor and research assistant. This data will be maintained in the Biomechanics and Human Performance Laboratory (McGill) for seven years after the completion of the project and will be destroyed afterwards. Only members of the research team (principal investigator, faculty supervisor/co-supervisors and research assistant) will have access to them. Your participation in this study will always remain confidential, including if the study is published or presented at a conference.

Pictures from the data collection sessions are sometimes helpful to use in publications or presentations without the participant's face shown. If you agree, may we use your picture in publications or presentations with your face not shown?

Yes: ___ No:___ for using your pictures taken during trials (without your face shown)

Dissemination of Results:

The study results will be explained in the primary investigator's Master's thesis. There is a possibility it will also be the topic of a published article in an academic journals or in a presentation at an industry conferences. The results will also be summarized in a report for PerfectFit Pointe, the company that provided the custom molded toe pads. The researchers also hope to present the results to local ballet schools and companies.

Questions:
If you have any questions about the research now or later, please contact Kristin Higgins by

email at kristin.higgins@mail.mcgill.ca.

Ifyouhaveanyethicalconcernsorcomplaintsaboutyourparticipationin thisstudy,andwantto speak with someone not on the research team, please contact the Associate Director, Research Ethicsat 514-398-6831orlynda.mcneil@mcgill.cacitingREBfilenumber22-08-007.

For written consent

Please sign below if you have read the above information and consent to participate in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. To ensure the study is being conducted properly, authorized individuals, such as a member of the Research Ethics Board, may have access to your (your child's) information. A copy of this consent form will be given to you and the researcher will keep a copy.

Participant's name (Please print):

Participant's signature:

Date:

For youth under 18, parent consent is required

Parent/Legal Tutor Consent

Guardian's name (Please print):

Guardian's signature:

Date:

Appendix Figure 9-3

Preliminary Survey

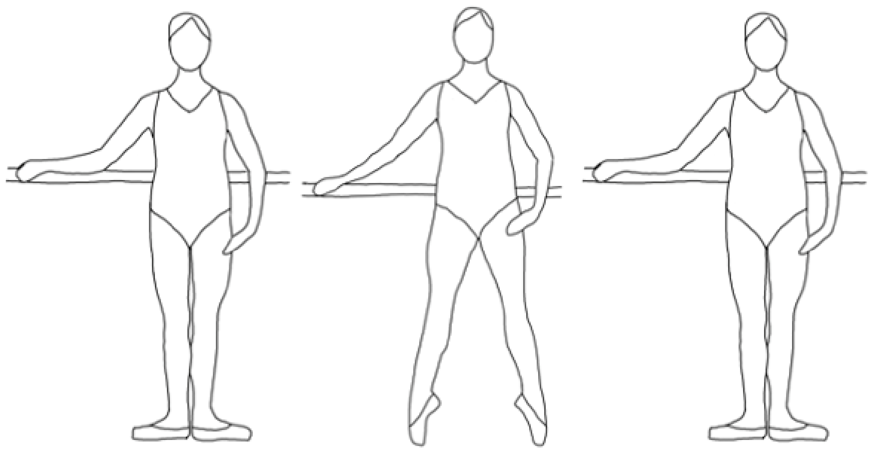
Please ask a researcher if you need any help or require clarification.

Age	
How long have you been dancing ballet?	
How long have you been dancing en pointe?	
How many hours per week do you typically dance ballet?	
How many hours per week do you typically dance en pointe?	
What ballet method have you primarily been trained in? (Cecchetti, RAD, Vaganova, etc.)	
If you have been trained with multiple methods, please list the others.	
When dancing, is your right or left side stronger?	
What brand are the pointe shoes you brought today?	
What is the style/model of the pointe shoes you brought today?	
What size are the pointe shoes you brought today? (Specify both length and width sizes)	
About how many hours of dancing have the pointe shoes you brought today been used for?	
What type of fit accessories (toe pads, toe spacers etc.) do you typically put in your shoes/wear while dancing?	
Have any customizations been done to your shoes such as cutting/scoring the arch or breaking the toe box? If so, please list them.	

Please circle the toe shape that is most like your own:

Appendix Figure 9-4

Rise on pointe performed by participants



Preparation: Standing in 1st position

Count 1: Begin rise to full pointe

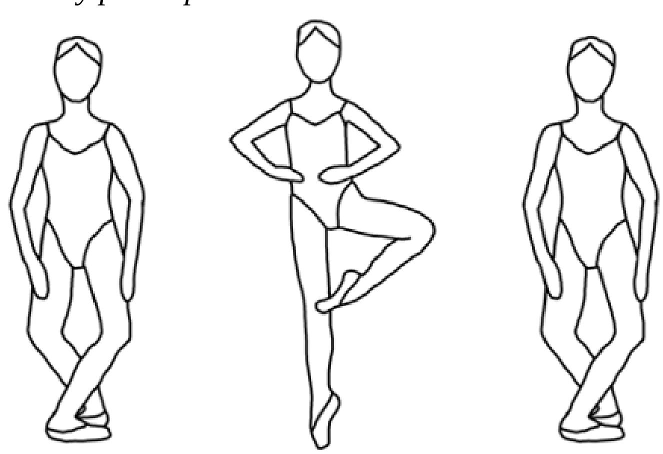
Count 2: Continue rise to full pointe

Count 3: Begin lower to flat foot

Count 4: Continue lower to flat foot

Appendix Figure 9-5

Balance in retiré performed by participants



Preparation: Standing in 5th position

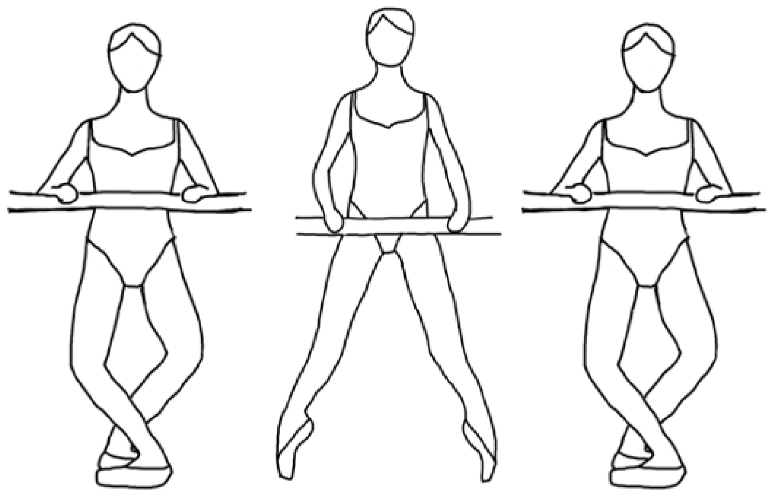
Count 1: Plié and relevé to retire position

Count 2 and 3: Balance on pointe, hands off the barre

Count 4: Lower to 5th position and plié

Appendix Figure 9-6

Échappé to second position performed by participants



Preparation: Standing in 5th position

Count 1: Plié and échappé to 2nd position

Count 2 and 3: Hold in 2nd position on pointe

Count 4: Close feet in 5th position and plié

Appendix Figure 9-7

End of Trial Survey
Participant ID:

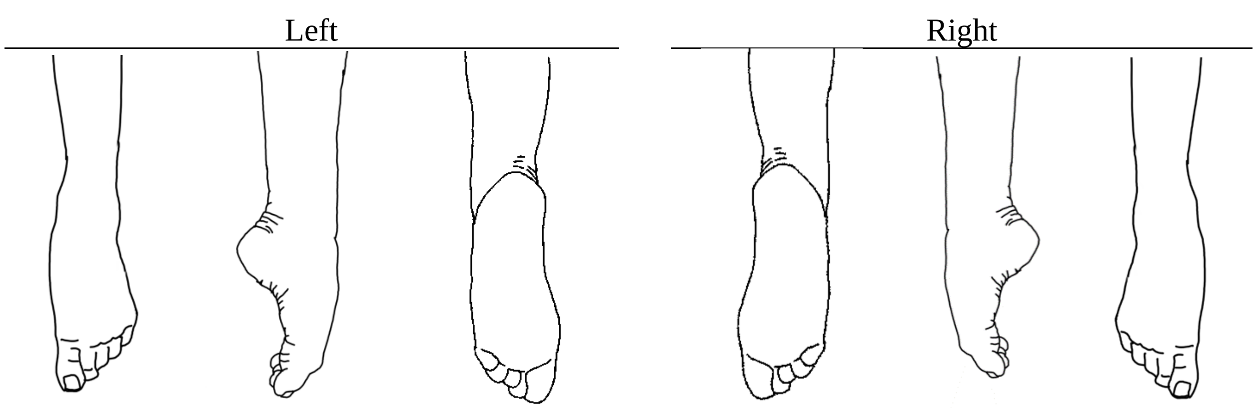
Padding condition:

Please ask a researcher if you need any help or require clarification.

1. Please respond to the following statements by rating them on a scale of 1 to 5 with the following scale:

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
a. Compared to how I usually wear my shoes, I was satisfied with the comfort of my shoes.	1	2	3	4	5
b. I was satisfied with the control I had over my shoes.	1	2	3	4	5
c. I felt stable while en pointe.	1	2	3	4	5
d. I was satisfied with the way my shoes fit.	1	2	3	4	5
e. I was satisfied by how the shoes moved with the movements of my toes.	1	2	3	4	5
f. I was satisfied with the overall performance of the shoes.	1	2	3	4	5

2. Please indicate the location of all pressure points using the provided diagram.



3. For each of your feet, please rate the following by drawing a "tick" mark on the scales. Each side is "least amount" or "most amount."

a. Overall comfort

Right Foot:

Not comfortable at all — Most comfortable condition imaginable

Left Foot:

Not comfortable at all — Most comfortable condition imaginable

b. Overall control

Right Foot:

Shoe did not move with the movements of my foot at all — Shoe moved with the movements of my foot perfectly

Left Foot:

Shoe did not move with the movements of my foot at all — Shoe moved with the movements of my foot perfectly

c. Overall stability

Right Foot:

I did not feel stable at all — I felt the most stable possible

Left Foot:

I did not feel stable at all — I felt the most stable possible

d. Overall pressure

Right Foot:

Most perceived pressure — No pressure at all

Left Foot:

Most perceived pressure — No pressure at all

Appendix Table 9.1

Principal component interpretations during rises

Sensor	PC	Description	Higher PC scores	Variance (%)
DHAL	1	Overall amplitude and shape	Higher pressure throughout motion	88.3
	2	Difference operator	Greater change in pressure during balance and lower phases	5.3
M1PIP	1	Overall amplitude and shape	Higher pressure throughout motion	79.5
	2	Phase shift	Delay during lower	5.9
	3	Phase shift	Delay in onset of pressure	5.4
M1MTP	1	Overall amplitude and shape	Higher pressure throughout motion	73.4
	2	Difference operator	Lower pressure during balance, higher pressure during rise and lower	11.3
	3	Phase shift	Delay in onset of pressure during lower	4.6
	4	Phase shift	Delay in overall onset of pressure	2.1
Do1MTP	1	Overall amplitude and shape	Higher pressure throughout motion	58.4
	2	Difference operator	Greater change in pressure throughout motion	14.6
	3	Phase shift	Delay in overall onset of pressure	10.8
	4	Difference operator	Higher pressure during mid rise and lower, lower pressure during beginning and end of balance	5.1
	5	Difference operator	Lower pressure during stand (beginning and end) and balance, higher pressure during rise and lower	2.4
L5MTP	1	Overall amplitude and shape	Higher pressure throughout motion	71.8
	2	Difference operator	Greater change in pressure throughout motion	12.4
	3	Difference operator	Greater change in pressure during end of balance/beginning of lower	4.8
	4	Difference operator	Lower pressure during beginning and end of motion	3.5

Appendix Table 9.2

Mean PC-scores and significance during rises onto pointe

Sensor	PC	Condition	Mean *PC-scores*	Standard Deviation	*F (p)*
DHAL	1	Gel	-1 786.74	12 106.92	1.91 (0.157)
		Custom	554.82	14 402.91	
		Participant's Choice	1 453.34	13 887.30	
	2	Gel	-565.82	2 785.33	1.46 (0.241)
		Custom	197.60	3 285.31	
		Participant's Choice	283.36	3 561.27	
M1PIP	1	Gel	896.87	3 983.40	6.64 (0.008)*
		Custom	-921.06	1 415.79	
		Participant's Choice	152.97	2 489.18	
	2	Gel	-10.53	792.18	2.68 (0.077)
		Custom	107.25	629.38	
		Participant's Choice	-89.10	739.85	
	3	Gel	-63.93	809.65	1.11 (0.336)
		Custom	98.73	379.25	
		Participant's Choice	-40.17	708.72	
M1MTP	1	Gel	2 238.53	5 250.04	23.32 (<0.001)*
		Custom	-1 509.11	3 491.18	
		Participant's Choice	-727.39	4 566.94	
	2	Gel	-111.76	2 120.05	1.30 (0.280)
		Custom	-109.55	1 517.63	
		Participant's Choice	176.77	1 811.75	
	3	Gel	73.12	1 075.51	0.68 (0.511)
		Custom	-85.95	868.36	
		Participant's Choice	89.11	1 166.13	
	4	Gel	-129.57	643.22	1.68 (0.196)
		Custom	187.13	794.46	
		Participant's Choice	-64.10	822.48	
Do1MTP	1	Gel	1 713.41	4 448.09	11.13 (<0.001)*
		Custom	-990.94	2 303.48	
		Participant's Choice	-825.33	3 143.68	
	2	Gel	-305.12	1 908.81	2.79 (0.071)
		Custom	-51.31	1 712.29	
		Participant's Choice	239.21	1 635.34	
	3	Gel	-32.03	1 389.83	2.06 (0.139)
		Custom	113.98	1 139.87	
		Participant's Choice	-372.68	1 040.74	
	4	Gel	77.16	988.94	0.17 (0.777)
		Custom	128.29	843.29	

		Participant's Choice	148.28	925.68	
		Gel	-100.14	817.19	
	5	Custom	198.24	481.28	4.09 (0.036)*
		Participant's Choice	-68.56	605.99	
		Gel	610.37	2 871.67	
	1	Custom	-858.75	2 044.72	12.54 (<0.001)*
		Participant's Choice	155.74	2 961.98	
		Gel	-82.73	1 160.46	
	2	Custom	-110.10	776.38	0.95 (0.394)
		Participant's Choice	111.36	1242.58	
L5MTP		Gel	-37.43	724.15	
	3	Custom	-7.99	550.76	0.51 (0.603)
		Participant's Choice	78.42	583.10	
		Gel	-5.45	728.00	
	4	Custom	-70.35	519.95	0.85 (0.433)
		Participant's Choice	61.08	451.45	

Note. Significant results are indicated with an asterisk.

Appendix Table 9.3

Principal component interpretations during balance in retire

Sensor	PC	Description	Higher PC scores	Variance (%)
DHAL	1	Overall amplitude and shape	Higher pressure throughout motion	89.8
	2	Difference operator	Larger change in pressure, smaller pressure during pliés, higher during balance	5.7
M1PIP	1	Overall amplitude and shape	Higher pressure throughout motion	77.2
	2	Difference operator	Larger change in pressure throughout motion, lower pressure during balance	13.5
M1MTP	1	Overall amplitude and shape	Higher pressure throughout motion	89.8
	2	Difference operator	Larger change in pressure, smaller pressure during pliés, higher during balance	5.5
Do1MTP	1	Overall amplitude and shape	Higher pressure throughout motion	83.8
	2	Phase shift	Delay in overall onset of pressure	8.5
L5MTP	1	Overall amplitude and shape	Higher pressure throughout motion	90.3

Appendix Table 9.4

Mean PC-scores and significance during balance in retiré

Sensor	PC	Condition	Mean *PC-scores*	Standard Deviation	F*(p)*
DHAL	1	Gel	-4 999.63	23 032.84	2.59 (0.100)
		Custom	412.90	29 342.076	
		Participant's Choice	4 443.03	28 354.59	
	2	Gel	-634.78	7 330.52	3.12 (0.052)
		Custom	-1 214.28	6 085.17	
		Participant's Choice	1 879.93	6 795.32	
M1PIP	1	Gel	683.64	3 457.05	4.37 (0.017)*
		Custom	-618.18	1 732.53	
		Participant's Choice	-112.24	1 886.60	
	2	Gel	25.19	1 084.71	0.85 (0.434)
		Custom	-123.88	965.81	
		Participant's Choice	97.89	1 114.83	
M1MTP	1	Gel	2 788.40	8 054.19	13.76 (<0.001)*
		Custom	-2 055.83	5 478.19	
		Participant's Choice	-411.53	7 021.63	
	2	Gel	-244.91	1 577.30	0.36 (0.042)
		Custom	290.28	1 519.86	
		Participant's Choice	-24.53	2 168.90	
Do1MTP	1	Gel	2 563.21	6 601.3	12.38 (<0.001)*
		Custom	-1 395.38	4 580.85	
		Participant's Choice	-1 166.00	5 680.75	
	2	Gel	91.05	2314.63	0.28 (0.757)
		Custom	2.61	1 500.16	
		Participant's Choice	-179.06	2 005.68	
L5MTP	1	Gel	1 107.13	4 029.95	11.48 (<0.001)*
		Custom	-1 364.84	2 358.13	
		Participant's Choice	169.32	4 113.01	

Note. Significant results are indicated with an asterisk.

Appendix Table 9.5

Principal component interpretations during échappés

Sensor	PC	Description	Higher PC scores	Variance (%)
DHAL	1	Overall amplitude and shape	Higher pressure throughout motion	83.1
	2	Difference operator	Larger change in pressure, smaller pressure during pliés, larger during échappé	9.8
M1PIP	1	Overall amplitude and shape	Higher pressure throughout motion	66.1
	2	Difference operator	Higher pressure throughout échappé, lower pressure during 2nd plié	16.9
	3	Difference operator	Higher pressure on pliés, delay in 1st plié	7.85
M1MTP	1	Overall amplitude and shape	Higher pressure throughout motion	84.1
	2	Difference operator	Higher pressure during pliés, less pressure during échappés	7.85
Do1MTP	1	Overall amplitude and shape	Higher pressure throughout motion	87.5
	2	Difference operator	Higher pressure during pliés	5.4
L5MTP	1	Overall amplitude and shape	Higher pressure throughout motion	92.8

Appendix Table 9.6

Mean PC-scores and significance during échappés

Sensor	PC	Condition	Mean *PC-scores*	Standard Deviation	F*(p)*
DHAL	1	Gel	-2 588.97	7 656.30	5.41 (0.007)*
		Custom	1 949.43	11 480.37	
		Participant's Choice	639.54	11 148.00	
	2	Gel	-442.88	2842.97	1.67 (0.203)
		Custom	156.69	4181.83	
		Participant's Choice	286.20	3556.26	
M1PIP	1	Gel	401.94	1984.84	4.98 (0.010)*
		Custom	-415.55	720.45	
		Participant's Choice	13.61	1264.60	
	2	Gel	128.38	800.91	2.74 (0.073)
		Custom	-137.08	458.11	
		Participant's Choice	8.70	864.47	
	3	Gel	-36.89	636.74	0.36 (0.701)
		Custom	18.99	254.83	
		Participant's Choice	17.90	536.62	
M1MTP	1	Gel	2 324.41	5804.0	12.83 (<0.001)*
		Custom	-1 260.98	4989.74	
		Participant's Choice	-1 063.43	4226.71	
	2	Gel	-108.63	1586.80	3.91 (0.026)*
		Custom	333.35	1424.79	
		Participant's Choice	-224.72	1788.59	
Do1MTP	1	Gel	2 196.71	6543.08	10.76 (<0.001)*
		Custom	-1 410.82	4298.73	
		Participant's Choice	-967.89	5650.14	
	2	Gel	-220.11	1835.08	0.98 (0.383)
		Custom	96.86	1039.76	
		Participant's Choice	-54.20	1233.79	
L5MTP	1	Gel	921.15	4383.91	8.45 (0.001)*
		Custom	-1 119.32	2977.27	
		Participant's Choice	198.17	4856.66	

Note. Significant results are indicated with an asterisk.

Appendix Table 9.7

Average normalized pressure significance during flat foot stance

Sensor	Condition	Mean (kPa/kg)	Standard Deviation	F*(p)*
DHAL	Gel	12.08	9.99	0.73 (0.487)
	Custom	13.81	11.73	
	Participant's Choice	13.00	9.78	
M1PIP	Gel	2.33	2.15	8.17 (0.001)*
	Custom	1.13	0.82	
	Participant's Choice	1.34	1.19	
M1MTP	Gel	6.56	4.37	10.37 (<0.001)*
	Custom	3.55	3.10	
	Participant's Choice	4.04	4.15	
Do1MTP	Gel	3.10	4.20	8.95 (0.002)
	Custom	1.36	1.54	
	Participant's Choice	0.95	2.21	
L5MTP	Gel	3.19	3.23	5.55 (0.006)
	Custom	2.16	2.54	
	Participant's Choice	2.29	2.54	

Note. Significant results are indicated with an asterisk.

Appendix Table 9.8

Results of factorial repeated measures ANOVAs during rises with training as the within group factor

Sensor	PC	Condition main effects F(*p*)	Training main effects F(*p*)	Interactions F(*p*)
DHAL	1	1.05 (0.357)	0.56 (0.460)	0.92 (0.407)
	2	1.59 (0.213)	0.37 (0.549)	0.26 (0.771)
	3	0.34 (0.716)	4.81 (0.037)*	0.26 (0.775)
M1PIP	1	0.74 (0.444)	0.04 (0.690)	0.06 (0.813)
	2	1.85 (0.167)	1.91 (0.179)	0.30 (0.110)
	3	0.72 (0.492)	0.93 (0.343)	1.35 (0.261)
M1MTP	1	19.61 (<0.001)*	1.99 (0.169)	0.32 (0.728)
	2	0.88 (0.421)	2.49 (0.126)	2.55 (0.087)
	3	0.29 (0.746)	0.01 (0.963)	0.75 (0.476)
	4	1.83 (0.170)	6.79 (0.015)*	0.21 (0.814)
Do1MTP	1	8.31 (0.003)*	0.99 (0.331)	0.28 (0.694)
	2	1.59 (0.214)	0.03 (0.867)	0.63 (0.539)
	3	1.28 (0.289)	2.77 (0.110)	0.32 (0.732)
	4	0.06 (0.888)	0.09 (0.774)	1.19 (0.304)
	5	3.79 (0.045)*	0.09 (0.763)	0.30 (0.678)
L5MTP	1	9.68 (<0.001)*	0.37 (0.548)	1.60 (0.213)
	2	0.84 (0.438)	6.23 (0.019)*	0.882 (0.412)
	3	0.14 (0.869)	0.72 (0.405)	1.26 (0.291)
	4	0.72 (0.490)	0.19 (0.668)	1.71 (0.190)

Note. Significant results are indicated with an asterisk.

Appendix Table 9.9

Results of factorial repeated measures ANOVAs during rises with toe shape as the within group factor

Sensor	PC	Condition main effects F(*p*)	Toe shape main effects F(*p*)	Interactions F(*p*)
DHAL	**1**	1.84 (0.168)	0.59 (0.448)	0.02 (0.981)
	2	0.24 (0.719)	0.02 (0.878)	0.49 (0.237)
	3	0.38 (0.684)	0.03 (0.856)	0.80 (0.457)
M1PIP	**1**	6.48 (0.010)*	0.008 (0.931)	0.82 (0.404)
	2	2.59 (0.084)	1.57 (0.221)	0.56 (0.573)
	3	1.07 (0.352)	0 (0.984)	0.29 (0.752)
M1MTP	**1**	22.73 (<0.001)*	0.001 (0.974)	0.48 (0.624)
	2	1.25 (0.295)	0.12 (0.728)	0.07 (0.931)
	3	0.66 (0.520)	0.46 (0.504)	4.70 (0.013)*
	4	1.67 (0.198)	1.19 (0.284)	0.71 (0.494)
Do1MTP	**1**	10.89 (0.001)*	0.39 (0.540)	1.07 (0.336)
	2	2.66 (0.081)	2.05 (0.166)	0.03 (0.967)
	3	1.94 (1.56)	2.89 (0.102)	0.63 (0.540)
	4	0.16 (0.783)	2.79 (0.109)	0.02 (0.943)
	5	3.88 (0.028)*	0.07 (0.789)	0.25 (0.778)
L5MTP	**1**	4.41 (0.017)*	0.58 (0.455)	0.17 (0.844)
	2	0.88 (0.420)	0 (0.998)	0 (0.954)
	3	0.41 (0.668)	1.845 (0.186)	1.85 (0.222)
	4	0.79 (0.461)	0.072 (0.790)	0.07 (0.851)

Note. Significant results are indicated with an asterisk.

Appendix Table 9.10

Results of factorial repeated measures ANOVAs during balance in retiré with training level as the within group factor

Sensor	PC	Condition main effects F(*p*)	Training main effects F(*p*)	Interactions F(*p*)
DHAL	1	1.57 (0.218)	2.279 (0.142)	0.59 (0.556)
	2	2.33 (0.107)	0.03 (0.854)	0.75 (0.477)
M1PIP	1	6.20 (0.006)*	0.47 (0.499)	0.44 (0.611)
	2	1.17 (0.319)	0.37 (0.549)	0.51 (0.602)
M1MTP	1	10.8 (<0.001)*	0.42 (0.049)*	0.59 (0.557)
	2	2.42 (0.098)	0.21 (0.654)	0.22 (0.752)
Do1MTP	1	9.98 (<0.001)*	0.59 (0.221)	0.28 (0.778)
	2	0.32 (0.542)	1.12 (0.317)	0.23 (0.867)
L5MTP	1	8.02 (0.001)*	1.05 (0.315)	1.41 (0.252)
	2	1.90 (0.159)	0.05 (0.825)	0.08 (0.927)

Note. Significant results are indicated with an asterisk.

Appendix Table 9.11

Results of factorial repeated measures ANOVAs during balance in retiré with toe shape as the within group factor

Sensor	PC	Condition main effects F(*p*)	Toe shape main effects F(*p*)	Interactions F(*p*)
DHAL	1	2.65 (0.080)	0.03 (0.862)	0.96 (0.391)
	2	3.04 (0.056)	1.67 (0.207)	0.17 (0.841)
M1PIP	1	4.12 (0.021)*	0.01 (0.916)	0.01 (0.853)
	2	0.75 (0.477)	1.08 (0.307)	1.08 (0.491)
M1MTP	1	14.22 (<0.001)*	0.07 (0.790)	0.07 (0.112)
	2	3.17 (0.050)*	0.004 (0.952)	0.004 (0.897)
Do1MTP	1	12.10 (<0.001)*	0.48 (0.578)	0.48 (0.495)
	2	0.26 (0.601)	0.06 (0.563)	0.06 (0.758)
L5MTP	1	4.24 (0.020)*	0.05 (0.832)	2.55 (0.087)

Note. Significant results are indicated with an asterisk.

Appendix Table 9.12

Results of factorial repeated measures ANOVAs during échappés with training level as the within group factor

Sensor	PC	Condition main effects F(*p*)	Training main effects F(*p*)	Interactions F(*p*)
DHAL	1	3.15 (0.037)*	0.91 (0.350)	0.90 (0.412)
	2	1.44 (0.245)	1.89 (0.181)	0.006 (0.994)
M1PIP	1	0.71 (0.495)	0.09 (0.762)	1.22 (0.303)
	2	3.67 (0.063)	3.23 (0.083)	4.62 (0.038)*
	3	0.41 (0.631)	0.34 (0.562)	0.612 (0.517)
M1MTP	1	10.23 (<0.001)*	4.15 (0.051)	1.13 (0.331)
	2	1.22 (0.303)	1.90 (0.179)	3.00 (0.058)
Do1MTP	1	8.32 (0.001)*	0.85 (0.367)	0.05 (0.953)
	2	0.41 (0.664)	0.09 (0.761)	0.48 (0.624)
L5MTP	1	5.51 (0.007)*	2.01 (0.168)	1.63 (0.205)

Note. Significant results are indicated with an asterisk.

Appendix Table 9.13

Results of factorial repeated measures ANOVAs during échappés with toe shape as the within group factor

Sensor	PC	Condition main effects F(p)	Toe shape main effects F(p)	Interactions F(p)
DHAL	1	5.45 (0.007)*	0.17 (0.681)	3.06 (0.055)
	2	1.58 (0.215)	0.09 (0.767)	2.26 (0.114)
M1PIP	1	4.70 (0.023)*	0 (0.984)	0.62 (0.496)
	2	2.91 (0.063)	0.06 (0.811)	0.83 (0.440)
	3	0.33 (0.723)	0.99 (0.329)	0.07 (0.937)
M1MTP	1	13.20 (<0.001)*	0.001 (0.970)	2.24 (0.116)
	2	4.00 (0.041)*	1.95 (0.174)	1.44 (0.246)
Do1MTP	1	10.26 (<0.001)*	0.96 (0.338)	1.04 (0.363)
	2	0.97 (0.388)	0.06 (0.814)	0.11 (0.893)
L5MTP	1	2.83 (0.068)	0.07 (0.798)	1.45 (0.244)

Note. Significant results are indicated with an asterisk.

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