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RESEARCH

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Effects of 4 weeks of foot exercise on subjective outcome and foot plantar pressure in elite adolescent dancers with hallux valgus: a pilot study

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Abstract

Background Dancers have a higher prevalence of hallux valgus (HV) than the general population. However, no reports specifically addressing treatment strategies for HV in dancers, or their effectiveness have been published. This study aimed to determine the effects of 4 weeks of foot exercises on subjective clinical outcomes, the HV angle, and change of foot plantar pressure during specific dance techniques.

Methods Thirteen female elite adolescent dancesport athletes (age: 16.4 ± 3.3 years) completed the program. The HV angle was measured based on foot photographs. Clinical assessments were performed using the visual analog scale for first metatarsophalangeal (1st MTP) joint pain, and the Foot and Ankle Outcome Score. The changes in plantar pressure during two dance techniques (demi-pointe and plié) were measured. The plantar pressure was measured in six areas of the foot. All of these parameters were compared before and after the intervention by using chi-square tests and Student's paired t-test (statistical significance: $p < 0.05$).

Results The HV angle was significantly reduced from 20.1° to 15.4° after the intervention. Participants reported an average subjective completion rate of 70.3% ± 14.6% over 3 weeks, exhibiting no significant differences despite an apparent trend toward improvement. Significant changes were noted in 1st MTP joint pain and subjective outcomes, and toe function significantly improved in the "paper" movement. The foot-exercise program changed plantar pressure distribution during the demi-pointe and plié techniques, with increased hallux pressure and decreased 2nd-5th MTP joint pressure.

Conclusions In elite adolescent dancesport athletes, 4 weeks of foot-exercise rehabilitation reduced the HV angle and improved in subjective outcome and function during the two dance techniques. Coaches should consider utilizing foot-exercise training programs in a dancer training program for HV.

Keywords Hallux valgus, Foot-exercise rehabilitation, Subjective outcome

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Introduction

Hallux valgus (HV) is a common deformity of the first metatarsophalangeal (1st MTP) joint. Its risk factors include genetics [1], sex [2], age [3], type of footwear (high-heeled shoes) [4], and muscle imbalance [5]. We are unaware of reports on HV occurring in any occupation other than that of professional dancing. In previous studies, the reported prevalence of HV among dancers was 54.9% [6], 40.0% [7], and 36.8% [8], whereas the reported prevalence of HV in the general population was 14.3% [9] and 7.8% [4]. Thus, existing data suggest that the prevalence of HV is higher among dancers than that among the general population. HV influences a person's quality of life [10–12], balance [13], and physical function [14, 15]. In dancers, HV also influences foot plantar pressure distribution [16]. For instance, a previous study revealed that the quality of life was influenced by HV in adolescent ballet dancers [17] and enlarged the retroversion of the pelvis during a plié [18].

Foot plantar pressure is frequently used in the evaluation of HV. In previous studies involving the general population, patients with HV exhibited a decrease in pressure distribution in the hallux area [19–21]. Other related findings include differences in the pressure distribution in the forefoot [22] and heel areas [19]. Foot plantar pressure has been used to assess changes before and after HV treatment. For instance, in a study on the effects of proximal crescentic osteotomy surgery for HV, not only was the HV angle improved, but significant changes in foot plantar pressure were observed, particularly in the hallux area [23]. In a study focusing on dancers, a larger HV angle was associated with a smaller pressure distribution in the hallux area [16]. However, no studies have investigated the impact of conservative treatment for HV on foot plantar pressure, whether in the general population or in dancers.

HV is usually treated via surgery and rehabilitation. However, in dancers, surgery is reserved for those who have retired from performing, because surgical correction may lead to a loss of range of motion at the 1st MTP [24]. Therefore, conservative treatment is necessary for dancers with HV. However, we are unaware of studies on HV rehabilitation treatment of dancers. In one study, manual stretching maneuvers had an immediate effect on the HV angle; specifically, it increased the plantar pressure of the hallux and first, second, and third metatarsals, and decreased the center of pressure excursion index when standing on one foot [25]. A previous study of the general population revealed that the toes-spread-out exercises can significantly increase the activation of the abductor hallucis muscle and decrease the HV angle in the horizontal plane during the exercises [26]. According to another study, skeletal muscle activity ("rock-paper-scissors" with the feet) can increase abductor hallucis muscle activity [27], indicating that it has potential in rehabilitation treatment for HV. In one study, a program comprising foot exercises (manual stretching and active extension of the 1st MTP, toes-spread-out exercises, a brief foot exercise, and toe curl exercises with a towel) decreased the HV angle and pain during walking [28].

This study aimed to determine the effects of 4 weeks of foot exercises on subjective clinical outcomes, HV angle, and changes in the foot plantar pressure during dance technique. We hypothesized that it would improve the subjective clinical outcome, reduce the HV angle, and improve the function of the 1st MTP joint during dance movements.

Methods

Study design

We performed a descriptive laboratory study to verify the effects of a 4-week rehabilitation program of supervised foot exercises on the HV angle, foot pain, subjective outcome, and change in foot plantar pressure during two dance techniques (demi-pointe and pile) in elite dancesport athletes with HV.

The survey was conducted after the dancers and their parents provided informed consent. The study was approved by the ethics committee of Waseda University (No.2022−541).

Participants

We recruited participants based on the records obtained from a school clinic. All participants had consulted with their coach or the school physician owing to HV, and their cases were documented in the clinic's records. The sample size was calculated using four parameters (tail[s]: 2; effect size dz: 0.8; α error prob [err prob]: 0.05; and power [1−β err prob] = 0.8) via G*Power (version 3.1.9.6). Thirteen elite adolescent dancesport athletes with HV volunteered for this study (age: 16.4 ± 3.3 years, weight: 48.1 ± 4.4 kg, height: 165.9 ± 3.8 cm, athletic career: 3.1 ± 1.1 years, training time: 5.3 ± 0.6 h/day), all of whom were part of a professional dancesport school. The inclusion criteria were an HV angle > 15° [2] and participating in the school dancesport training program in the past year. Participants were excluded if they had any orthopedic or other foot injuries or symptoms (such as pain and swelling) in the past year, were undergoing treatment for HV or other foot injuries, or were using nonsteroidal anti-inflammatory drugs or analgesic drugs.

Measurements

HV angle

For HV angle measurements, we used foot photographs (HVAp). The participants stood with their feet shoulder-width apart, in the normal standing position, with their hands on the anterior superior iliac spine and their eyes looking forward. A measurement camera (SX430is; Canon, Tochigi, Japan) was set in position at an inclined angle of 15° relative to the vertical line passing through the tip of the second toe, and a still frame of the screen was obtained [13].

The HVAp was measured by an investigator with 5 years of experience in HV research using ImageJ software (Ver. 1.53k; Bethesda, MD, USA). First, a tangent line (AB) was drawn from the medial edge of the big toe (A) to the inner edge of the head of the first metatarsal bone (B). Point C was marked such that lines AB and BC were at the same distance from the contact point B along the medial side of the first metatarsal. The angle (α) between lines AB and BC was defined as the metatarsal angle [13]. (Figure. 1).

Subjective outcome

We evaluated 1st MTP pain was evaluated using a visual analog scale (VAS) (0=no pain, 10=unbearable, severe pain). The 1st MTP positions (plantar, medial, and dorsal) were confirmed by a physical therapist, whereas the scale was self-reported by the dancers. The participants' subjective experience of HV was measured via the Foot and Ankle Outcome Score (FAOS). The FAOS is a patient-reported instrument that covers five domains (symptoms, pain, daily functioning, sport/recreational functioning, and quality of life), each scored between 0 (bad) and 100 (good) [29].This survey is normally used to assess the subjective outcome or toe function of patients with HV before and after the first tarsometatarsal fusion or proximal first metatarsal osteotomy surgery [30] or distal soft tissue realignment procedure and medial eminence resection surgery [29]. A previous study revealed that the FAOS has higher construct validity, reliability, and responsiveness in patients with HV than those in the general population and is a useful patient-based tool in assessing these patients [29].

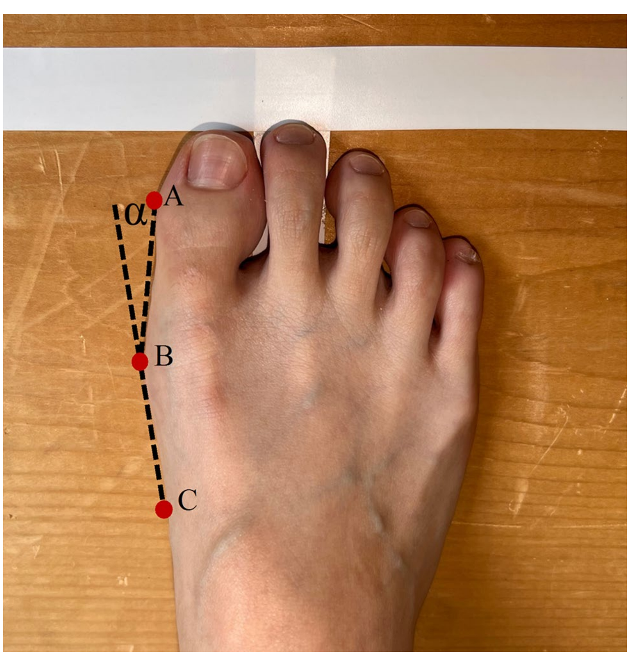

Fig. 1 Measure method of hallux valgus angle by photography

Toe function

In a previous study, the foot "rock-paper-scissors" movement proved useful in testing toe function [31]. In this study, we used it to measure the change in toe function after intervention compared to that before the intervention. To evaluate whether the "rock-paper-scissors" movement was performed correctly, we followed the criteria from the prior study. The criterion for the "rock" movement was "complete flexion of all the toes," that for the "paper" movement was "no contact of the toes while spreading them out," and for the "scissors" movement, both "full flexion and extension" were required [32]. A movement was deemed "correct" only if it met these standards; otherwise, it was considered "incorrect." The accuracy of the test was confirmed by two physical therapists who verified the movements at the same time(Fig. 2 green box; A: rock, B: paper, C: scissors).

Foot plantar pressure

This study was conducted at the participants' school. The foot plantar pressure was measured using a plantar pressure sensor (F-scan II; Tekscan, Japan). (Figure. 3) The two sensors were placed on a level floor and the foot reference line was placed flat on the sensor at a 60°external rotation to the sagittal plane (120° in total) of the participant. Based on the manufacturer's recommendations, we performed calibration for each participant with alternating single-leg standing, first left and then right. The testing areas were divided, as in a previous study, into hallux (1), toe (2), 1st MTP (3), 2-5 MTPs (4), mid-foot (5), and heel (6) (Fig. 4) [21].

Procedures

Dance technique

We compared the foot plantar pressure before and after the intervention by having the participant perform the demi-pointe and the plié techniques based on the first position (first position: feet in extra rotation, with heels together and 120° opening angle). The demi-pointe technique required the participant to face forward with the knee extended and the trunk upright. In this position, the participant performed maximum plantar flexion of the ankle. The demi-pointe was divided into four phases (pre-demi-pointe: maintaining the first position, demi-pointe up: raising the heel at a constant speed, demi-pointe: achieving maximum plantar flexion of the ankle, demi-pointe down: lowering the heel at a constant speed

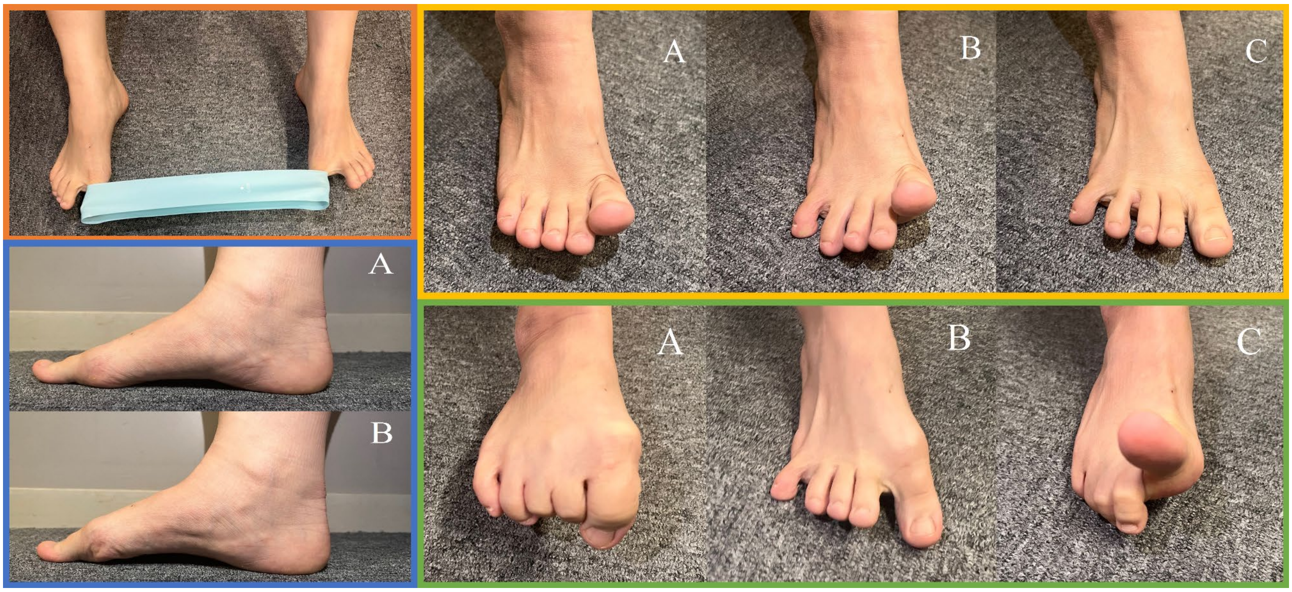

Fig. 2 Rehabilitation program. The orange boxes indicate 1st MTP joint abduction via manual stretching, the yellow boxes indicate the toes-spread-out exercise, the blue boxes indicate the short foot exercise, and the green boxes indicate the rock-paper-scissors movement

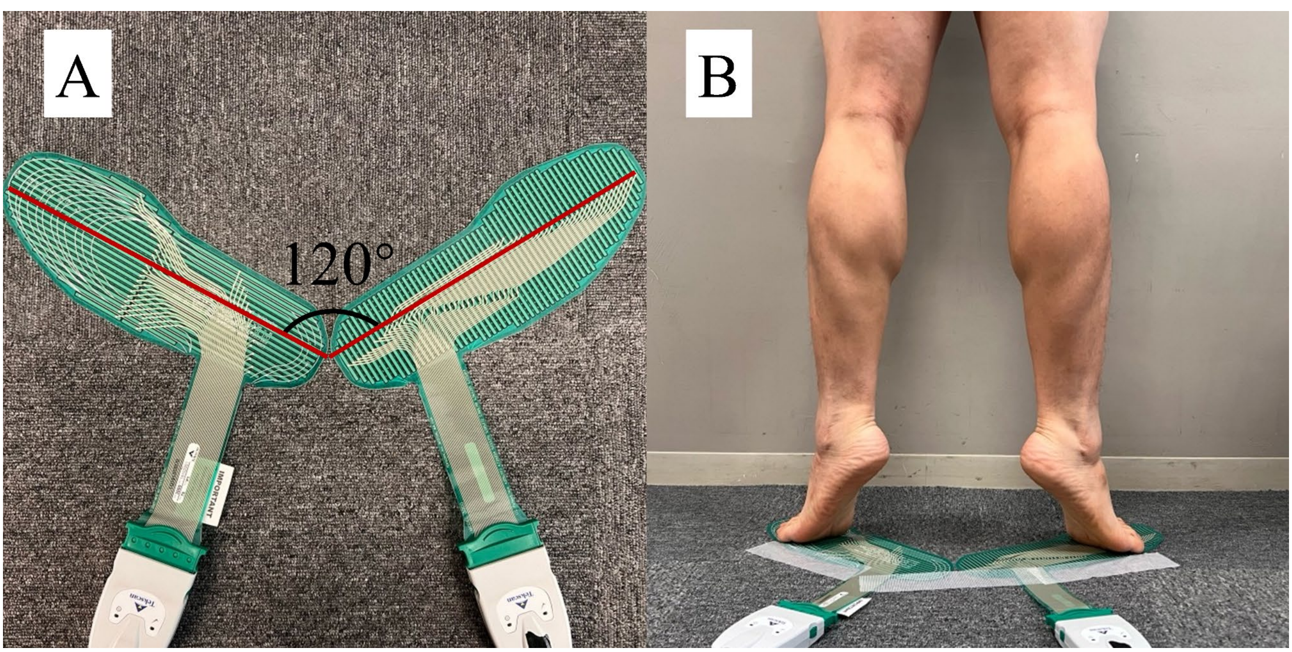

Fig. 3 Experimental setup illustrating (**A**) the sensor installation and (**B**) the limb positioning in demi-pointe

until the heel touches the ground). We instructed all participants to aim for maximum height during the demi-pointe-up phase.

The grand plié (plié) technique had the same starting position as the demi-pointe. The technique commenced with the dancer keeping the knee orientated in the pointe position and bending the knee joint to the maximum while keeping the trunk upright and maintaining the first position. The plié was divided into four phases (pre-plié: maintaining the first position, plié down: flexing the knees at a constant speed until the heels lift off the ground, plié: reaching the maximum knee flexion angle; plié up: extending the knees and lowering the heels back to the ground). During the foot plantar pressure measurements for the demi-pointe and plié techniques, all dancers performed the movements with a 120° turnout.

A metronome was used to time each phase of the two dance techniques, with each phase set to 5 s. Before the foot plantar pressure was measured, each dancer completed no fewer than two practice trials.

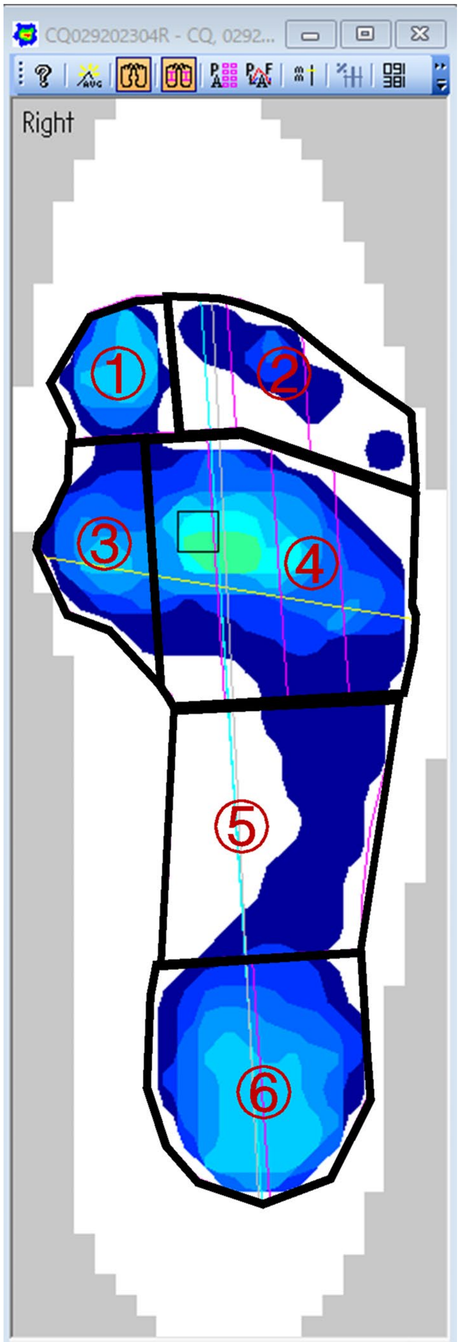

Fig. 4 Division of plantar pressure

Rehabilitation program

We designed the foot exercise self-rehabilitation program according to previous studies and clinical experience. It included 1st MTP joint abduction via manual stretching [25], the toes-spread-out exercise [33], a brief short foot exercise [28], and foot "rock-paper-scissors" exercises (Fig. 2) [27].

All participants were educated on the foot-exercise program, and we asked them to focus on feeling their muscles being activated during the exercises. All the participants performed the same routine with bare feet, 7 days a week for 4 weeks. Each participant received an illustrated, narrative brochure containing information on the foot-exercise program. Individuals were followed up once a day via a mobile phone application regarding the completion status of the program. Additionally, once a week, an in-person follow-up was conducted for all participants to provide guidance, correct any potential issues with the program, and inquire regarding their subjective completion of the rehabilitation program over the past week.

Data analysis

Data were analyzed using IBM SPSS Statistics for Windows, Version 28.0 (IBM Corp., Armonk, NY, USA). In the statistical analysis, we used the intraclass correlation coefficient (ICC[1,1]) to determine the intrarater reliability of the HV angle. In accordance with a previous study, ICC values <0.50, ≥ 0.50 and <0.75, ≥ 0.75 and <0.90, and ≥ 0.90 indicate poor, moderate, good, and excellent reliability, respectively [34].

The levels of subjective completion of the rehabilitation program were descriptively reported using percentages and standard errors of the mean. Chi-square tests were used to compare toe function before and after the intervention. The HV angle, VAS score, FAOS, and foot plantar pressure were first analyzed using the Shapiro–Wilk test for normality of data distributions. Thereafter, the paired t-test and Wilcoxon signed-rank sum test were used to compare all the data, according to the data distribution. A p-value <0.05 was regarded as reflecting a statistically significant result for all tests.

For each testing area, Cohen's d effect sizes and associated 95% confidence intervals (95% CI) were calculated to estimate the magnitude and precision of the treatment effect after rehabilitation. Effect sizes were interpreted as follows: >0.80 large, 0.50–0.79 moderate, 0.20–0.49 small, and <0.20 trivial [35].

Results

HV angle

The HV angle was significantly decreased following the intervention compared to that before the intervention (20.1° ± 3.1° vs. 15.4° ± 4.5°; decrease 4.7°, $p<0.001$, $d=1.29$; 95% CI, 2.46 to 6.75; power [$1-\beta$ err prob] = 0.989). The ICC (1,1) value of 0.910 indicated excellent reliability.

Subjective completion of the rehabilitation program

During the weekly follow-ups, all participants reported their subjective completion level for the program: 68.0% ± 14.8% in the first week, 70.5% ± 15.6% in the second week, and 72.3% ± 14.3% in the third week, with an overall average of 70.3% ± 14.6%. Although the subjective completion level seemed to improve, no significant differences were observed.

Foot pain and subjective outcome

The 1st MTP plantar pain significantly differed before and after the intervention (2.2 ± 1.9 vs. 0.9 ± 1.2; decrease: 1.3, $p = 0.021$, d = 0.78; 95% CI, 0.23 to 2.34; power [1 − β err prob] = 0.734), whereas no significant differences were observed in the medial and dorsal aspects of the 1st MTP. The overall FAOS did not significantly differ before and after the intervention; however, the symptoms domain did ($p < 0.05$) (Table 1). Particularly, significant changes were observed on the second question ("Do you feel grinding, hear clicking, or any other type of noise when your foot/ankle moves?"; $p = 0.006$) and fourth question ("Can you straighten your foot/ankle fully?"; $p = 0.004$) before and after the intervention.

Toe function measurements

Based on the judgement of the two physical therapists, the "paper" movement significantly differed before and after the intervention ($p = 0.041$), but not the other two movements.

Foot plantar pressure

After the foot-exercise program, the hallux %pressure during the demi-pointe technique had increased ($p = 0.003$, d = 0.72; 95% CI, -0.07 to -0.02; power [1 − β err prob] = 0.668) and the 2–5 MTP joint %pressure during the plié technique had decreased ($p < 0.001$, d = 0.86; 95% CI, 0.02 to 0.08; power [1 − β err prob] = 0.809) (Fig. 5).

In the demi-pointe technique, the hallux %pressure had significantly increased during the demi-pointe ($p = 0.042$, d = 0.47; 95% CI, -0.07 to -0.001; power [1 − β err prob] = 0.535) and demi-pointe down ($p = 0.024$, d = 0.532; 95% CI, -0.07 to -0.01; power [1 − β err prob] = 0.641) phases. Significant changes were also observed in the 1st MTP area during the pre-demi-pointe ($p = 0.017$, d = 0.57; 95% CI, 0.01 to 0.09; power [1 − β err prob] = 0.701) and demi-pointe up ($p < 0.001$, d = 1.00; 95% CI, -0.15 to -0.06; power [1 − β err prob] = 0.992) phases (Fig. 6, demi-pointe technique).

In the plié technique, the toe %pressure had significantly increased during the pre-demi-pointe ($p < 0.001$, d = 0.98; 95% CI, -0.09 to -0.03; power [1 − β err prob] = 0.991) and plié ($p = 0.001$, d = 0.84; 95% CI, -0.08 to -0.01; power [1 − β err prob] = 0.955) phases. The 1st MTP %pressure had significantly decreased during the plié down phase ($p = 0.009$, d = 0.67; 95% CI, 0.017 to 0.105; power [1 − β err prob] = 0.836), and the 2–5 MTP %pressure had significantly decreased during the plié phase ($p < 0.001$, d = 0.97; 95% CI, 0.01 to 0.13; power [1 − β err prob] = 0.966) (Fig. 6, plié technique).

Discussion

This research was a pilot study of the effect of 4 weeks of foot-exercise-based self-rehabilitation for elite dancesport athletes with HV. The exercise program decreased the HV angle, foot pain intensity, and subjective foot outcome. Moreover, foot plantar pressure changed in the participants' dance technique.

The HV angle is an important clinical measurement in diagnosing of an HV deformity [2]. In previous studies, the most common treatments to decrease the HV angle were surgery [30] and rehabilitation, such as taping [36, 37], splinting [38], and foot exercises [28]. However, for an adolescent or a dancer, surgery is not desirable, because it generally influences the range of motion and function of the 1st MTP joint and the development of the foot [39, 40]. In such patients, rehabilitation is the treatment of choice. We are not aware of previously published studies on rehabilitation treatment for HV in dancers. In studies of participants from the general population, taping or splinting yielded an acute reduction in the HV angle [37, 38]. In one report, 1 month of foot-exercise rehabilitation yielded a significant HV angle reduction of 1.7° [38]. Their result was similar to ours (decrease 4.7°). Our results suggest that a foot-exercise rehabilitation program comprising 1stMTP joint abduction via manual stretching, toes-spread out exercises, a brief foot exercise, and foot "rock-paper-scissors" movements reduces the HV angle in elite adolescent dancesport athletes.

In previous studies, an HV manifested in subjective symptoms in the 1st MTP joint [2, 41].In this study, 1st MTP pain was decreased after 4 weeks of foot-exercise rehabilitation, particularly the 1st MTP plantar pain. In another study, HV usually occurred along with 1st MTP bone hyperpronation [42] and translocation of the sesamoid bones [43], resulting in overloading of the tibial sesamoid bone, which is painful. However, metatarsal bone rotation can cause the joint capsule to be malpositioned, resulting in 1st MTP pain [44]. In this study, the 4 weeks of foot-exercise rehabilitation might have restored the 1st MTP bone to its original location and decreased sesamoid bone overloading, decreasing participants' pain. Further, owing to HV, the hallux area pressure decreases and that in the first and second MTP bone head area significant increases [19]. In a study, the HV angle was significantly negatively correlated with hallux plantar pressure in the demi-pointe technique [16]. In another study, as the hallux function was improved in patients with HV, the MTP bone-head plantar pressure decreased [45]. Another result of this study was that the 1st MTP joint %pressure had significantly decreased after the intervention. This may explain why the 1st MTP joint plantar pain was decreased after the exercise program.

Although the subjective outcome as a whole had not significantly changed after the exercise program, the

Table 1 Comparison of the clinical outcomes evaluated using FAOS

FAOS	Pre-intervention	Post-intervention	*p*
Symptoms (total)	68.4 ± 15.5	78.6 ± 15.8	0.036
Do you have swelling in your foot/ankle?	0.4 ± 0.7	0.5 ± 1.0	0.549
Do you feel grinding, hear clicking, or any other type of noise when your foot/ankle moves?	1.4 ± 1.0	0.6 ± 0.7	0.006
Does your foot/ankle catch or hang up when moving?	0.6 ± 0.4	0.4 ± 0.7	0.165
Can you straighten your foot/ankle fully?	3.0 ± 1.8	1.3 ± 1.1	0.004
Can you bend your foot/ankle fully?	2.9 ± 1.8	2.2 ± 1.6	0.312
How severe is your foot/ankle joint stiffness after first wakening in the morning?	0.4 ± 0.6	0.6 ± 1.2	0.337
How severe is your foot/ankle joint stiffness after sitting, lying, or resting later in the day?	0.3 ± 0.5	0.2 ± 0.4	0.584
Pain (total)	86.0 ± 12.7	89.1 ± 11.5	0.323
How often do you experience foot/ankle pain?	1.2 ± 1.2	0.8 ± 0.7	0.213
Twisting/pivoting on your foot/ankle	0.8 ± 0.8	0.8 ± 1.0	1.000
Straightening foot/ankle fully	0.5 ± 0.5	0.4 ± 0.7	0.502
Bending foot/ankle fully	0.5 ± 0.7	0.6 ± 0.8	0.721
Walking on a flat surface	0.5 ± 0.9	0.2 ± 0.4	0.219
Going up or down stairs	0.6 ± 0.9	0.3 ± 0.4	0.219
At night while in bed	0.3 ± 0.5	0.4 ± 1.0	0.721
Sitting or lying	0.2 ± 0.4	0.2 ± 0.6	0.721
Standing upright	0.4 ± 0.7	0.2 ± 0.4	0.436
ADL (total)	93.1 ± 10.6	97.1 ± 3.6	0.160
Descending stairs	0.5 ± 0.7	0.5 ± 0.5	0.673
Ascending stairs	0.5 ± 0.7	0.3 ± 0.5	0.190
Rising from sitting	0.2 ± 0.4	0.1 ± 0.3	0.584
Standing	0.5 ± 0.8	0.3 ± 0.1	0.436
Bending to the floor/pick up an object	0.3 ± 0.6	0.0 ± 0.0	0.104
Walking on a flat surface	0.2 ± 0.6	0.3 ± 0.5	0.584
Getting in/out of car	0.2 ± 0.6	0.0 ± 0.0	0.190
Going shopping	0.3 ± 0.8	0.2 ± 0.4	0.721
Putting on socks/stockings	0.1 ± 0.3	0.0 ± 0.0	0.337
Rising from bed	0.0 ± 0.0	0.1 ± 0.3	0.337
Taking off socks/stockings	0.1 ± 0.3	0.0 ± 0.0	0.337
Lying in bed (turning over, maintaining foot/ankle position)	0.1 ± 0.3	0.0 ± 0.0	0.337
Getting in/out of bath	0.3 ± 0.6	0.0 ± 0.0	0.104
Sitting	0.2 ± 0.4	0.1 ± 0.3	0.584
Getting on/off toilet	0.7 ± 0.9	0.2 ± 0.4	0.028
Heavy domestic duties (moving heavy boxes, scrubbing floors, etc.)	0.5 ± 0.8	0.0 ± 0.0	0.053
Light domestic duties (cooking, dusting, etc.)	0.1 ± 0.3	0.0 ± 0.0	0.337
Sports (total)	83.5 ± 14.3	87.7 ± 11.3	0.324
Squatting	0.5 ± 0.7	0.3 ± 0.5	0.273
Running	1.1 ± 1.0	0.7 ± 0.8	0.137
Jumping	0.8 ± 0.9	0.8 ± 0.7	1.000
Twisting/pivoting on your injured foot/ankle	0.6 ± 0.7	0.3 ± 0.5	0.165
Kneeling	0.3 ± 0.6	0.4 ± 0.7	0.673
QOL (total)	92.3 ± 8.1	89.4 ± 9.7	0.398
How often are you aware of your foot/ankle problem?	0.7 ± 0.9	0.9 ± 1.0	0.549
Have you modified your lifestyle to avoid activities potentially damaging to your foot/ankle?	0.1 ± 0.3	0.4 ± 0.5	0.040
How much are you troubled with lack of confidence in your foot/ankle?	0.3 ± 0.8	0.4 ± 0.7	0.721
In general, how much difficulty do you have with your foot/ankle?	0.2 ± 0.4	0.1 ± 0.3	0.584
Total scores	424.3 ± 47.0	439.1 ± 37.9	0.219

All scores are displayed as means ± standard deviations

FAOS = Foot and Ankle Outcome Score, ADL = activities of daily living, QOL = quality of life. ns: no significant difference between before and after

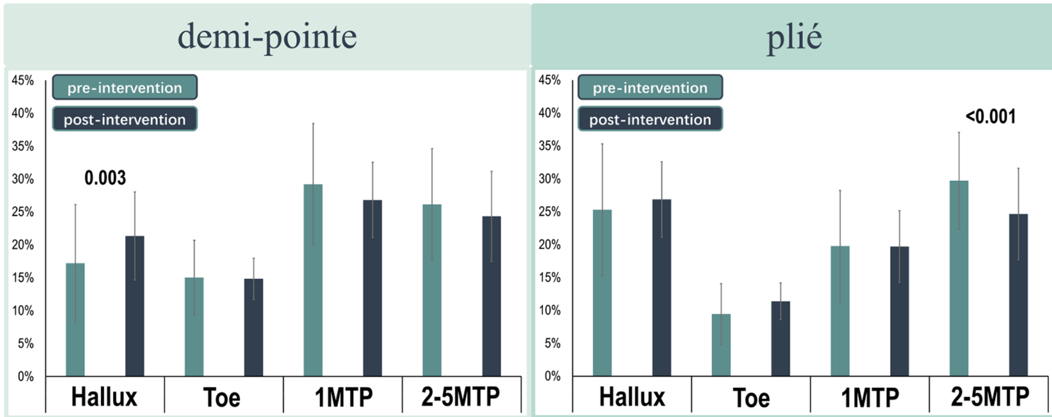

Fig. 5 Difference between the pre and post intervention in demi-pointe (left) or plié(right). Significant p-value was expressed above the bars

symptom domain of the FAOS did, and particularly two questions in this domain (Table 1). This is in line with previous studies that revealed that an HV is usually accompanied by a painful click [41] and restrictions in the range of motion [2]. The 4 weeks of intervention might have improved the alignment of the 1st MTP joint and the hallux to reduce the HV, as suggested by the two questions on the joint flexibility and painful clicks.

In this study, we used the "rock-paper-scissors" movements to measure toe function and evaluated dance techniques to determine the effect of foot-exercise self-rehabilitation for HV in elite adolescent dancesport athletes. The 4-week foot-exercise program improved participants' toe function and changed foot plantar pressure. A previous study revealed that the "rock-paper-scissors" movements involve the intrinsic foot muscles, such as the extensor hallucis brevis and abductor hallucis [27]. The observed improvements in participants' ability to complete the "rock-paper-scissors" movements may indicate that the intrinsic foot muscles were improved.

The demi-pointe and plié are basic techniques in dance [46]. A previous study indicated that the HV angle influences the hallux plantar pressure in dancers when they perform the demi-pointe technique [16]. However, we could not find any research on the effect of foot-exercise self-rehabilitation among dancers with HV. In a previous study of participants from the general population, an 8-week foot-exercise program reduced the HV angle and foot pain [28]. In another study, the HV angle was reduced and the subjective outcome was improved after 4 weeks of a foot-exercise program [38]. In this study, 4 weeks of foot exercises not only reduced the HV angle and improved the subjective outcome and toe function but also increased the hallux plantar pressure in the pre-demi pointe phase of the demi-pointe technique (Fig. 7) and in the pre-plié phase of the plié technique (Fig. 8).

Previous studies have revealed significantly lower toe flexor strength in older [14] and young female adults [47] with HV compared with those in healthy individuals. One study focusing on patients with HV revealed significantly lower plantar flexion and abduction strength of the 1st MTP joint and a significantly lower pressure distribution in the hallux area compared with those in healthy individuals (without HV) [48]. This suggests that the decreased muscle strength of toe-related muscles, such as the flexor hallucis brevis and abductor hallucis, in patients with HV leads to a reduced pressure distribution in the hallux area. In our study, the rehabilitation program included the toes-spread-out exercise, a brief foot exercises, and the foot "rock-paper-scissors" exercise. These exercises aim to enhance foot muscle strength, which may explain the observed increase in pressure distribution in the hallux area after the 4-week rehabilitation program.

Limitations

This study had several limitations. In previous studies, HV was mainly diagnosed using X-ray imaging. In this study, we used a fast but accurate method to measure the HV angle in elite adolescent dancesport athletes. In the future, X-ray imaging should be used to measure the HV angle and other important factors in HV, including the intermetatarsal angle.

In this study, the HV angle changed more than that in other studies. A possible explanation is that the participants in this study were adolescents with mild HV. To our knowledge, no studies have been conducted on the difference between the demi-pointe and plié techniques in terms of foot plantar pressure. In our study, the differences in foot plantar pressure before and after the intervention were not the same between the two techniques. This may be because the two techniques involve different positions with different points of the foot being in contact with the floor.

In another study, foot pain was reduced after the rehabilitation program [38]. However, in this study, only

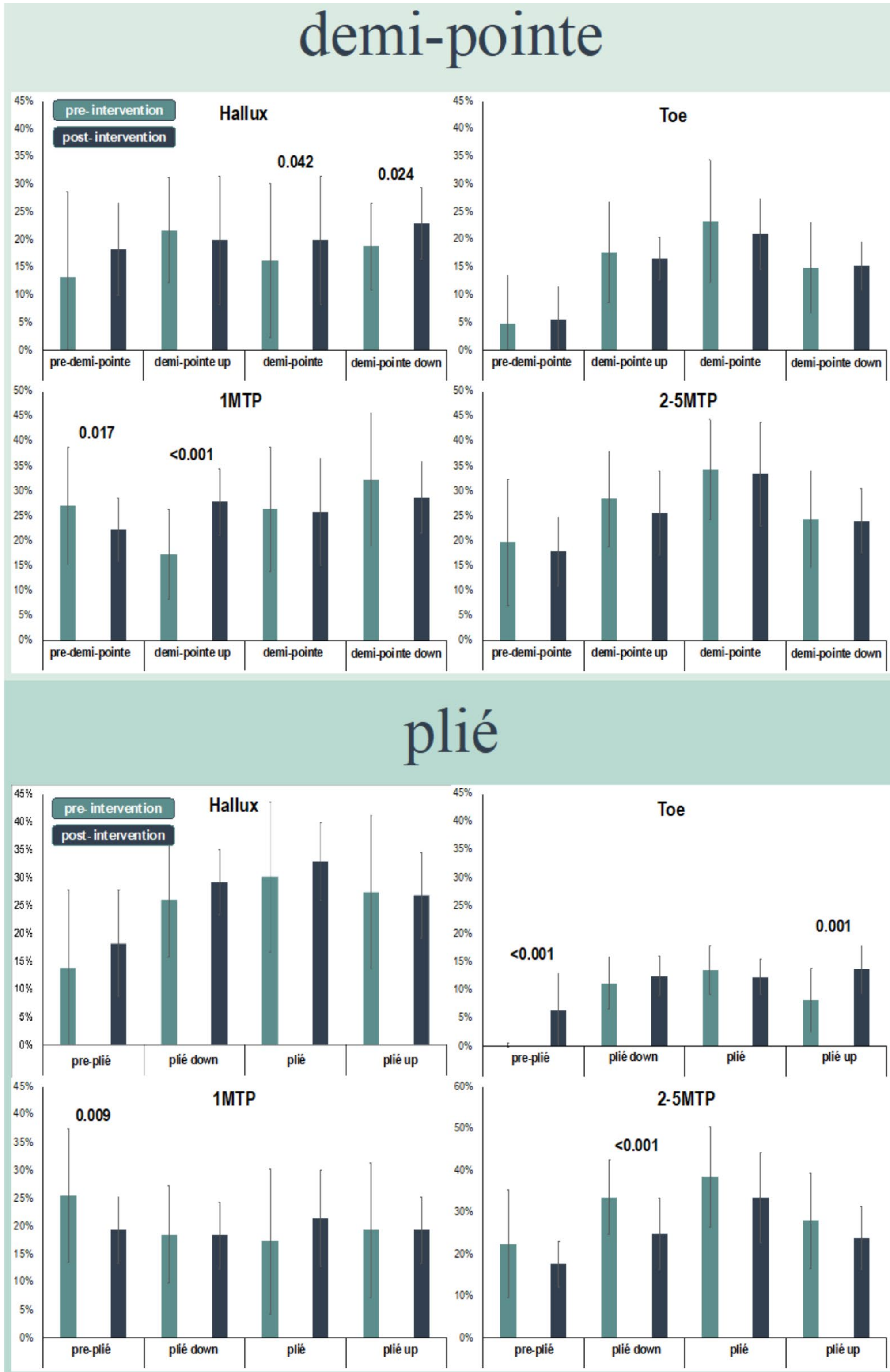

Fig. 6 Difference between the pre and post intervention on each phase in demi-pointe or plié. Significant p-value was expressed above the bars

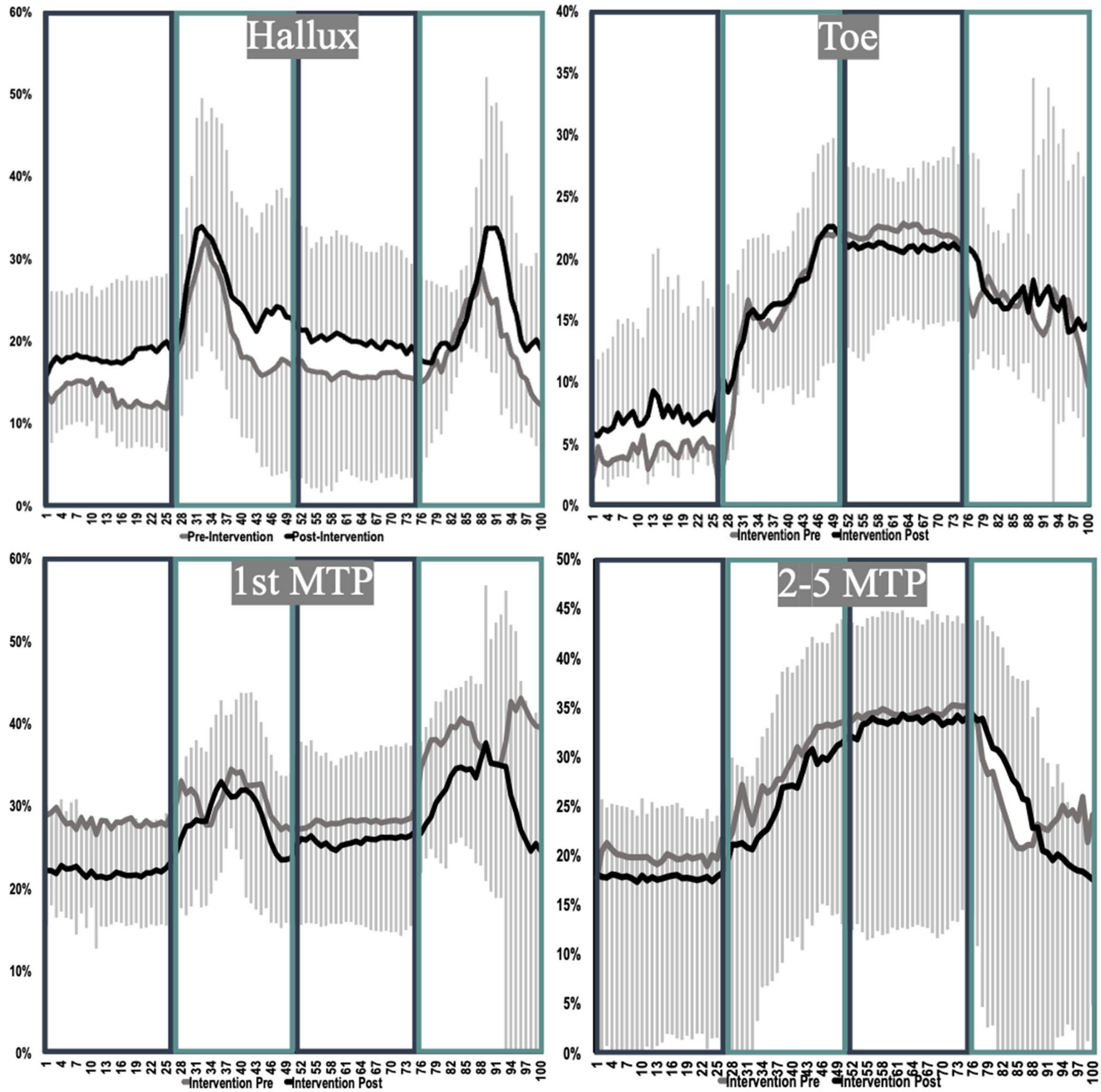

Fig. 7 %pressure during the demi-pointe technique in each area. Each phase was divided to pre-demi-pointe, demi-pointe up, demi-pointe, demi-pointe down from left. Gray bars represent the error bars

the 1st MTP plantar pain was significantly improved. This may be because the participants in this study trained≥40 h a week, and they did not interrupt their training routine during the intervention period.

In this study, the follow-up period was 4 weeks. However, we did not determine the duration of the effect. Therefore, we could not establish whether the program improved the subjective outcome and foot plantar pressure during dancing.

Conclusion

A 4-week foot-exercise self-rehabilitation program was used among elite adolescent dancesport athletes who exhibited an HV angle; consequently, their foot subjective outcomes and toe function were improved, especially the hallux pressure. Future studies should be conducted to determine the effects after the rehabilitation program, such as those on the intrinsic foot muscles, via surface electromyography and the change in performance in the dance routine.

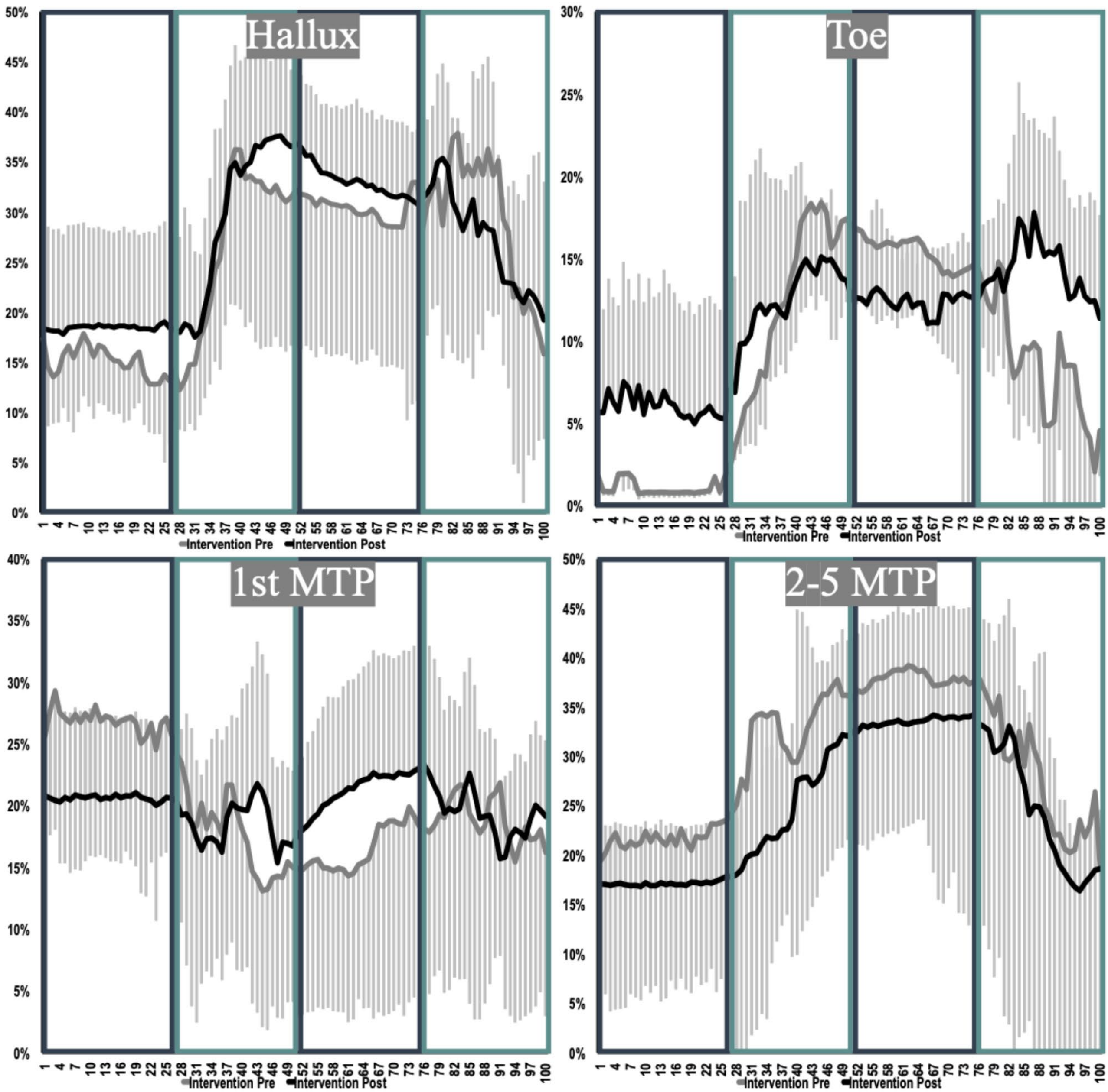

Fig. 8 %pressure during the demi-pointe technique in each area. Each phase was divided to pre-plié, plié down, plié, plié up from left. Gray bars represent the error bars

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Author contributions
Zijian Liu (Conceptualization, Data curation, Methodology, Visualization, Writing – original draft, Writing – review & editing), Yicheng Zhong and Shuo Chen (Data curation, Methodology), Hirofumi Tanaka and Hirofumi Katsutani (Data curation, Methodology), Hiroki Yabiku (Data curation, Visualization), Takumi Okunuki (Conceptualization, Data curation, Methodology), Yanshu Li (Writing – original draft, Writing – review & editing), Tsukasa Kumai (Conceptualization, Data curation, Methodology, Visualization, Writing – original draft, Writing – review & editing, Supervision).

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Data availability
The datasets generated and/or analysed during the current study are not publicly available due [This study is still ongoing, and further discussions will be conducted in the future] but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The survey was conducted after the athletes and their parents informed consent. Ethical approval for this study was granted by the Waseda University Human Research Ethics Committee (No. 2022 – 541).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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