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The effects of a 6-week sand- vs. Land-based jump training programme on frontal plane knee angle and jump performance in adolescent female football players*

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ABSTRACT

Our study investigated the effects of a six-week jump-training intervention (sand- vs land- based incorporated in a warmup), on frontal plane knee angle and jump performance of adolescent female football players. Fifty-six females were randomly allocated to either the SAND or LAND group. Thirty-nine females completed the programme twice weekly and were eligible for analysis. Two-dimensional frontal plane projection angle (FPPA), countermovement jump (CMJ) and reactive strength index (RSI) (10–5 repeated jump test) were measured 1-week pre- and post-intervention. Analysis of covariance was used to model post-intervention group differences. Compatibility curves were used to visualise parameter estimates alongside *p*- values, and surprisal (S) value transforms. Mean difference ($\bar{X}$) and compatibility intervals (CI) (95|75%) for FPPA for SAND vs. LAND were $\bar{X}$ = 1.29° (−0.11 to 2.69°|0.49 to 2.10°) for the dominant limb, and $\bar{X}$ = 1.80° (0.56 to 3.04°|1.09 to 2.51°)| for the non-dominant limb. Interval estimates for jump performance were imprecise and unclear. The data indicates that including a sand surface within a jump training intervention could be beneficial when aiming to improve knee control in asymptomatic adolescent female football players, with no apparent detriment to jumping performance.

Clinical trials registration: The trial was registered with clinicaltrials.gov prior to study recruitment (NCT04502615).

KEYWORDS
Sand; frontal plane projection angle; jump performance

Introduction

Football has a higher incidence of anterior cruciate ligament (ACL) injury and associated burden, than other sports (Moses et al., 2012). Female players are at a 2–3 times higher risk for an ACL injury compared to their male counterparts (Montalvo et al., 2019; Waldén et al., 2011). The incidence of ACL injury for predominantly youth football players (0.12 per 1000 exposure hours; Crossley et al., 2020) is higher than those playing at senior elite (0.06–0.11; Hägglund et al., 2009; Waldén et al., 2011), and collegiate level (0.06–0.09; Agel et al., 2016; Hootman et al., 2007). These statistics showcase the importance of developing effective ACL injury risk reduction strategies in female youth players to facilitate their progress to senior football with optimal wellbeing and performance (Crossley et al., 2020).

Whilst anatomical differences and hormonal changes are potential causative mechanisms for female ACL injury (Belanger et al., 2013; Meeuwisse et al., 2007), an excessive knee valgus position upon landing is frequently proposed as an important risk factor (Dingenen et al., 2015; Hewett et al., 2016; Numata et al., 2018; Stuelcken et al., 2016). Interventions which aim to reduce landing valgus angles in females could be integral to (p)rehabilitation programmes for ACL injuries. Exercise-based ACL injury prevention programmes, such as the FIFA 11+ (Bizzini & Dvorak, 2015), 11+ kids (Franchina et al., 2023) and the Prevent injury and Enhance Performance programme (Mandelbaum et al., 2005) often include neuromuscular exercises focusing on lower-limb alignment during landing (Arundale et al., 2018; Dai et al., 2014. These exercise-based neuromuscular programmes reduce ACL injuries by 38% in predominantly youth female footballers (Crossley et al., 2020), and appear more effective when aimed at early or pre-teens (Ramos et al., 2024) compared with late teens or young adults (Myer et al., 2013). However, the optimal combination of training components within these programmes remains unclear, and a lack of implementation and adherence (Donaldson et al., 2017; Slauterbeck et al., 2019) may reduce the ‘real world’ effect of injury prevention programmes to as low as 13% (Åman et al., 2018). The reported barriers to adopting these programmes include a lack of performance enhancement effects, coach buy-in, lack of player motivation, concerns regarding the duration of the programmes and player fatigue at the start of a training session (Donaldson et al., 2019; Franchina et al., 2023; O'Brien et al., 2021; Ross et al., 2023).

Exercise- based interventions which 1) reduce ACL injury risk, 2) are of short duration (e.g. <20 min) inducing low fatigue

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levels, and 3) improve (or maintain) performance measures (e.g. jump performance) are more likely to achieve better adherence and compliance (Herrington, 2010). Short-duration jump-training programmes (<20 minutes or incorporated within a warmup) have been shown to be as effective at reducing landing knee valgus and potential ACL injury risk as those with additional balance and strength training components (Aerts et al., 2015; Colclough et al., 2018; Herrington, 2010; Petushek et al., 2019). Additionally, concomitant increases in performance measures similar to long-duration interventions are reported (Herrington, 2010; Kato et al., 2008). However, training programmes are commonly performed on hard surfaces (concrete, wood, synthetic floors), which increases musculoskeletal loading and may reduce performance and increase injury risk (Pereira et al., 2021).

The use of sand as an alternative training surface to enhance neuromuscular performance and reduce injury risk has been advocated (Binnie et al., 2014), with jump-training and plyometric tasks on sand during injury prevention and rehabilitation programmes highlighted as one of its main uses in professional football (Richardson et al., 2023). Sand's absorption qualities reduce peak deceleration forces encountered upon impact with the training surface (Barrett et al., 1998; Gaudino et al., 2013), which may be particularly pertinent during high-intensity exercise such as jumping where large demands are placed on the lower limbs (Impellizzeri et al., 2008).

Empirical evidence for sand-based jump- training has revealed a plethora of advantages when compared to a firm surface including: reductions in muscle soreness, exercise induced muscle damage, and recovery time (Impellizzeri et al., 2008; Miyama & Nosaka, 2004; Singh et al., 2014; Binnie et al., 2014). Whilst sand's reported ability to dissipate ground reaction forces may affect the velocity and specificity of movement patterns (Alcaraz et al., 2011), and might reduce jumping performance (Giatsis et al., 2018, 2022) via reduced efficiency of the stretch-shortening cycle; equivocal improvements to land-based training (~6–7 weeks' duration) for a range of performance measures, including sprinting, jumping (Pereira et al., 2021; Vuong et al., 2023), balance and agility (Arazi et al., 2014; Bonavolontà et al., 2021; Hammami et al., 2020; Mirzaei et al., 2014, Ozen et al., 2020), have been demonstrated across a range of team sports, including amateur football. Adaptations such as enhanced motor unit recruitment and increased activation of synergists when training on sand compared to firm surfaces are amongst the proposed mechanisms cited for the noted performance effects (Arazi et al., 2014; Pinnington et al., 2005; Sharma & Chaubey, 2013). Thus, despite the potential for the increasing compliance and shock absorption qualities of sand to compromise the optimal storage of and utilization of elastic energy (Bishop, 2003), a positive training response can still be apparent in jumping performance.

Studies investigating the acute effects of surface have reported compatible effect sizes pertaining to reductions in ACL risk factors in females such as knee abduction moment (Richardson et al., 2020, 2024) during single-leg jump tasks ($\bar{X}$ =0.17N.m/kg^{-1}.m^{-1}; 0.02–0.31N.m/kg^{-1}.m^{-1}), and decreased knee valgus (assessed via 2D motion capture) during a single- leg landing task ($\bar{X}$ = 4.2°; 1.4–7.0°) on sand compared to firm surfaces (Richardson et al., 2021). Whether the effects observed were practically meaningful is unclear and the studies require further replication. Nevertheless, the aforementioned evidence highlights sand may offer a beneficial environment for (p)rehabilitation programmes. Whether the acute responses observed predict and translate into long-term beneficial responses to knee alignment upon landing, alongside positive responses in performance parameters (e.g. maintenance or improvement in jumping performance) when incorporated into a training programme requires investigation.

Therefore, the aim of our study was to investigate the effect of a 6-week jump training intervention on both a sand and land surface (added to a warmup), on the landing knee valgus and jumping performance of adolescent female football players. We hypothesised *a-priori* that sand would reduce the FPPA (established via 2D motion capture) compared to land-based training whilst maintaining similar jump-based performance measures.

Materials and methods

Participants

Fifty-nine female participants who were training and playing in the English Football Association Emerging Talent Centre within a University institution were recruited for the study. We did not perform formal sample size (*n*) calculations in the planning stages to control for either β error rates or planning for precision. Our sample size justification is based upon resource limitations and time constraints (Lakens & Ravenzwaaij, 2022). As such our study should be considered non-confirmatory in nature. Three females were excluded, one for previous ACL injury and two for a lower limb injury within the last six months. Subsequently, 56 participants completed pre-testing and were randomised to intervention surface (via a computer-generated system). 47 completed a minimum of 75% of all training sessions across the 6-week intervention period but 8 of these were lost to follow-up. 39 participants (age: 12.62 ± 1.44 years; body mass: 49.2 ± 10.3 kg; stature: 158.8 ± 7.8 cm; PHV: 1.2 ± 1.2 years) completed pre- and post-testing sessions (1 week prior to and post intervention) and met the threshold for compliance to be included in the analysis. All participants were 16 or under, had no history of ACL injury or other knee pathology, previous significant lower limb fracture or surgery and had been injury free for six months prior to data collection. All participants and parents were informed about the purpose and content of the study. Written informed consent was provided by all participants, and all parents gave their written informed consent for their child to participate in the study. The study was approved by the University's ethics committee, in accordance with the Declaration of Helsinki. The trial was registered with clinicaltrials.gov prior to study recruitment (NCT04502615).

Procedures

A randomised pre-post-trial design was implemented, with participants attending testing on two occasions (1-week pre and post a 6-week intervention). Testing took place at Teesside University within the Biomechanics Laboratory. Participants' age, mass, height and sitting height were determined, along with their dominant leg (decided by the leg they prefer to kick a ball with). Prior to testing, a standardised dynamic warmup was performed led by a member of the research team with significant experience as a strength and conditioning coach, and included squats, lunges, pogos, snap downs, countermovement jumps, single leg Romanian deadlifts, spiderman's and thoracic rotations.

Subsequently, participants performed a single leg landing (SLL) task (right and left leg), a maximal CMJ test, and a repeated 10–5 jump test. The SLL task was the functional test chosen for the landing task due to its use in a clinical setting as well as its high test-retest reliability (intraclass correlation coefficient = 0.87, Herrington et al., 2017). Following a demonstration, participants performed three familiarisation trials of the SLL task on each leg, to orient themselves to the task prior to data collection. Participants then performed five landing trials for each leg with a standardised rest phase (1 minute) between each jump.

For the SLL task, participants were instructed to step off a 30 cm box (Foam Plyometric Box, Perform Better Ltd., UK) landing with the opposite leg onto a predetermined floor marker 30 cm from the box holding the position (Herrington & Munro, 2010). Throughout testing participants were required to wear retro reflective markers positioned over dark tight fitted clothing to allow for visualisation of markers. Markers were placed on the anterior superior iliac spine (ASIS), mid-tibiofemoral joint (TFJ) and mid-ankle mortise bilaterally. Midpoints were determined using a standard tape measure. Two-dimensional (2D) frontal plane projection angle (FPPA) of knee valgus alignment was measured during the SLL task (Herrington & Munro, 2010). A high-speed digital video camera (Quintic GigE 1mp, Quintic Consultancy Ltd, West Midlands, UK) recording at 250 frames per second was positioned 3 m anterior to the participants landing target at the height of the participant's knee and aligned perpendicular to the frontal plane. Images captured were imported into a digitising software program (Quintic 33, Quintic Consultancy Ltd, UK) for analysis. The valgus angle of the knee was recorded as the angle formed between the line from the ASIS and mid TFJ markers and the line from the mid TFJ and mid-ankle mortise markers (Herrington & Munro, 2010). The angle was captured using the frame which corresponded to the lowest point of the landing phase. Positive and Negative FPPA values reflected knee valgus and varus respectively. The mean FPPA value from the five trials on each leg during the SLL task was used for analysis. One investigator digitized all the data from all participants. Thirty randomly selected knee valgus angle videos (a combination of left and right leg landing, pre and post intervention, sand and land surfaces) were re-assessed to establish the intra-rater reliability.

Following completion of the SLL task participants were then asked to complete two performance tests (with a standardised 2-minute rest period between them). As within the SLL task they were given practice trials to reduce confounding from habitation. The first test was a countermovement jump (CMJ), which is a reliable method of measuring lower body power (Markovic et al., 2004). Participants stood on a force platform (built into the laboratory floor). Each foot was placed on an individual force plate. Participants were then asked to squat down, keeping their hands on their hips and subsequently jump as high as they were able. Whilst in flight they were instructed to keep their hands on their hips and keep their legs straight. Participants were instructed to land in the same position they took off from (i.e. not forward or backwards). Participants performed 3 maximal efforts with the mean height being used for analysis. The jump height was estimated using the impulse momentum data from the force platform. The second test was the 10/5 repeated jump test to evaluate the participants reactive strength index (RSI). The test required the participants to execute 10 maximal rebound jumps (attempting to minimise ground contact time between jumps). Of the 10 jumps, the 5 that displayed the greatest RSI were used for analysis. The 10/5 test has been shown to be a reliable measure both between trials and across days (Beattie & Flanagan, 2015). The 10/5 test was measured using the same in-ground force plates noted for the CMJ test. As with the CMJ test participants were instructed to keep their hands on their hips throughout the jump phase and each of the 10 repeated jumps. One trial of the test was all that was required for data analysis purposes. All participants refrained from strenuous muscular exercise for ~24 h prior to testing (pre and post intervention).

Interventions

Participants were randomised into one of two groups (SAND or LAND) via a computer-generated system. Both groups performed a progressive jump training protocol (see supplementary Material), which involved a series of jumping exercises that were added to their usual warmup routine (lasting 5–10 minutes per session) prior to a 2-hour training session twice weekly for a period of 6 weeks. The jumping protocol was either carried out on LAND or a SAND surface. For the SAND group bespoke sandpits were made (1 m × 1 m) with a 10 cm depth of sand. Where jump-landing and CMJs were executed from a box a 30 cm height was used (LAND group), with a 40 cm box utilised for the SAND group to ensure the drop height was consistent between groups. All participants were able to train and play for the Emerging Talent Centre as normal during the intervention period. Participants were then invited back for post-testing the week following completion of the 6-week protocol. A personal visit by the lead researcher (sports physiotherapist) with each of the tactical and strength and conditioning coaches who deliver the training sessions was organized to inform them of the jumping programme. During these meetings, the coaches received specific information on the programme (written handout, instruction, demonstrations, and videos) on how to correctly instruct and perform the exercises. The lead researcher attended training at least once each week to ensure accurate instruction and progression of the programme exercises. The programme aimed to improve the participants' jump landing technique and jumping ability and progressed in difficulty across the 6 weeks. The jumping protocol and progression were based on previous programmes aiming to improve jumping technique and prevent lower-extremity injuries (Aerts et al., 2015; Colclough et al., 2018; Myer et al., 2006). Sessions were supervised to ensure all exercises were performed correctly, and to monitor adherence of the participants, with attendance registered across the duration of the trial, and any reasons for non-attendance documented. All participants were required to complete a minimum of 75% of all sessions for their data to be included in the analysis (Paterno et al., 2004). Eighty-four per cent of participants reached this threshold.

Statistical analysis

All data were processed through R-Studio (version: 2022.12.0 + 353), example code is provided in supplementary material. Intra-rater reliability of frontal-plane projection angle was estimated through a two-way mixed effects interclass correlation coefficient ($ICC^{3,1}$) as well as the typical error of the estimate which was calculated as the standard deviation of the differences divided by the square route of two (Hopkins et al., 2009).

Mean frontal-plane projection angle (dominant and non-dominant limb), CMJ jump height and 10/5 reactive strength index (RSI) were calculated for each participant for further statistical analysis. A general linear model was chosen to assess differences between groups using the lme4 package (Bates et al., 2015), controlling for baseline differences using an analysis of covariance (ANCOVA) (Vickers & Altman, 2001). The behaviour of the residuals were visually inspected and were acceptable for the assumptions of normality (via QQ plots), homogeneity of variance and linearity using the performance package (Lüdecke et al., 2021).

Estimated marginal means differences, within and between groups, were computed through the emmeans package (Lenth et al., 2018) and presented as unstandardised effects sizes and compatibility (confidence) intervals (CI). We have chosen to use estimation as the primary approach to inform our inferences with the greatest emphasis on the point estimate (most compatible with the data) alongside discussing the range of effects within the compatibility interval (CI). Here we interpret the values within the CI (e.g. 95%) as 'highly compatible with our observed data under the background statistical assumptions' of the model (Greenland, 2019). We also present exact p-values to 3 digits and interpret the observed p as a measure of compatibility of the data with the statistical model (encompassing all background assumptions/hypotheses) with zero effect as the null hypothesis (H_o) (Greenland et al., 2016). The p-values were subsequently converted into surprisal values (s-value) by taking the negative base-2 logarithm of the p-value [S-value = $-\log_2$ (p-value)] (Rafi & Greenland, 2020). Surprisal values provide the amount of refutational information against the target hypothesis, assuming all background test assumptions are true, and can be interpreted via a simple coin-tossing exercise where the observed data are no-more surprising than x consecutive heads when flipping an unbiased coin. E.g., a surprisal value of 3.2 would be no more surprising than observing 3 consecutive heads (to the nearest integer) in a row or provides 3 bits (binary digits) of information against the target hypothesis (e.g. H_o) assuming all other test assumptions were true.

Given the pitfalls of dichotomising results as statistically significant and non-significant (McShane et al., 2019) and noting that 95% CI represent just one arbitrary dichotomization of possible parameter values, we plotted compatibility curves (or p-value functions/consonance curves) which display a range of values (hypotheses) compatible with the observed data across a range of P-values and S-values (Rafi & Greenland, 2020). These compatibility curves contain horizontally stacked CI at every possible level. These curves enable the reader to interpret the compatibility (and surprisal value) of any given effect size with the observed data given the model. For example, it may be pertinent to consider the minimal effect size of practical interest here. This also allows interpretation of statistical equivalence, for example if the extent to which the compatibility intervals fall within the minimal positive or negative change (Lakens et al., 2018). For additional clarity we present effect sizes for both 95% and 75% CI which correspond to approximately 4 and 2 bits of information. Thus, values at the end of a 75% CI have 2 bits of information against them (i.e. as surprising as 2 consecutive heads in a row).

Determining the practically meaningful difference in FPPA is challenging as there is no obvious anchor and any value chosen may be sensitive to baseline. In such cases researchers are often required to default to a distribution approach (0.2 × between-player *SD)* (Hopkins et al., 2009) to estimate the smallest worthwhile change (SWC) although there are noted shortcomings to this approach (Tenan & Caldwell, 2022). In the absence of other options, we felt that SWC was appropriate (Datson et al., 2022) to inform our statistical and importantly scientific inferences. Whilst we provide possible thresholds, we urge the reader to interpret these cautiously and even apply their own thresholds when interpreting the data. For the CMJ we used the work of Datson et al. (2022) who comprehensively reviewed methods for setting a target difference in female soccer players, including surveying experienced practitioners' perception, with the lower 95% compatibility intervals for perceived practically important changes to be 2.1 cm. For RSI there is no recognised practically relevant value that we are aware of, and 0.2 multiplied by the between-participant SD results in a clear underestimation 0.04 m/s which is common with this approach (Datson et al., 2022). Hughes et al. (2022) observed a 0.25 m/s difference between elite and sub-elite female Gaelic football players, with their sub-elite players ~0.16 m/s higher than our youth players. Thus, a value between > 0.08 to >0.15 m/s would be the minimum change required for a move category in either direction. Thus, we chose 0.08 m/s here.

Results

Study flow and characteristics

Fifty-nine female adolescents were assessed for eligibility, with 3 excluded prior to the start of the intervention due to knee injury. Fifty-six were then randomised into either the LAND ($n = 28$) or SAND ($n = 28$) intervention. Participant flow is presented in Figure 1. Baseline characteristics for the included participants are presented in Table 1.

Excellent intra-rater reliability was observed ($ICC^{3,1}$ 95% confidence intervals 0.99 to 1.00) with a typical error of 0.59 (95% CI 0.47 to 0.79) degrees. The observed point estimate (most compatible effect size) and associated 95% interval estimates are compatible with a reduction (i.e. favourable) in FPPA in dominant ($\bar{X} = -5.13°$; 95% CI = −6.75 to −3.51° and non-dominant limbs ($\bar{X}$ =-4.36°; 95% CI = −5.97 to −2.74°) pre-post testing. However, the observed reductions were not in relation to a control condition. The estimates for the countermovement jump ($\bar{X}$ −0.56; 95% CI= −2.04 to

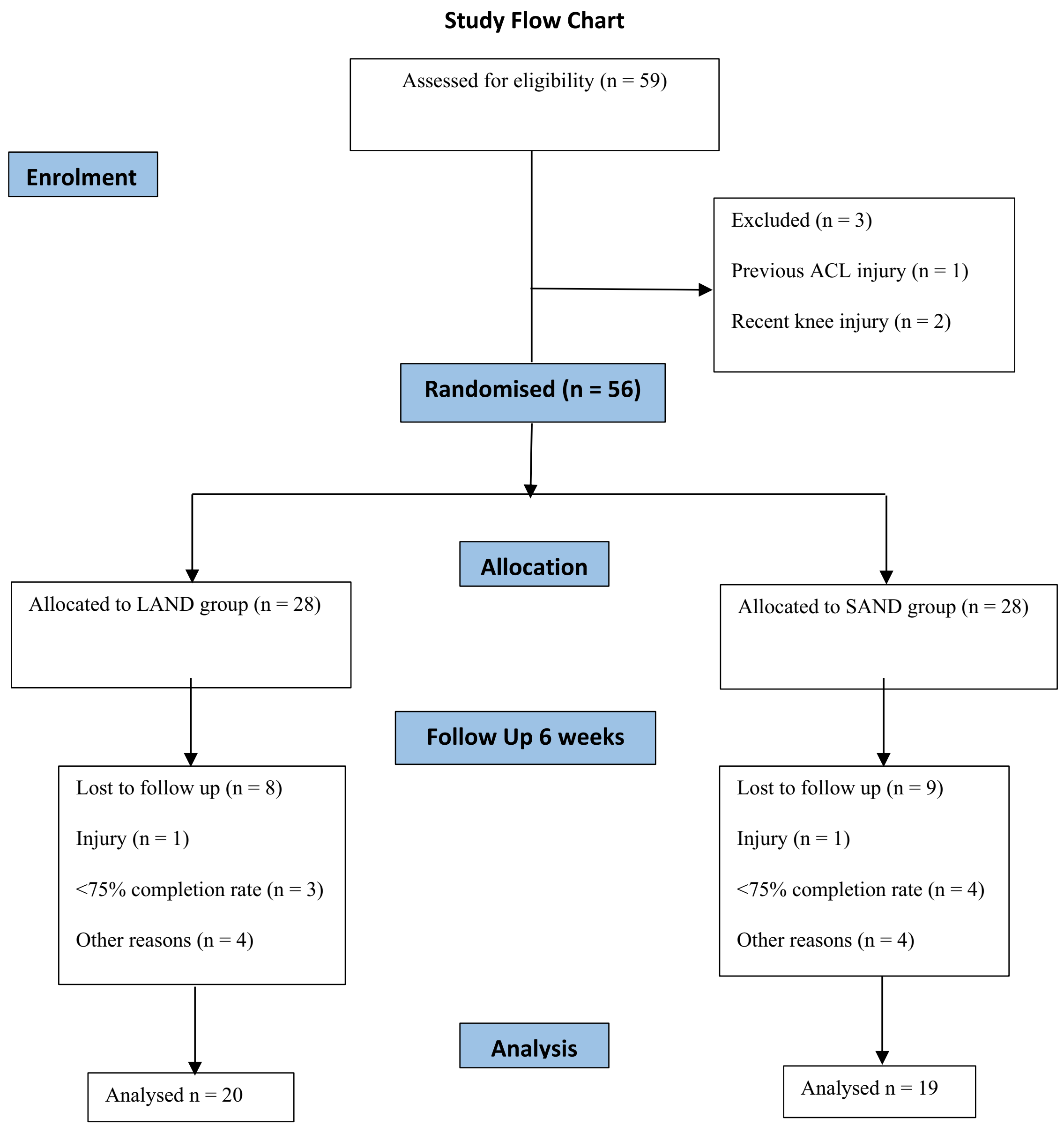

Figure 1. Flow of participants through the intervention (LAND & SAND groups).

Table 1. Summary (mean ± standard deviations) and inferential statistics across outcome measures for within and between-group changes. All values presented to 3 significant digits.

	Pre intervention Mean ± SD		Within-group differences Mean difference (95% CI)		Between group differences (Land – Sand)	
Outcome measures	Land	Sand	Land	Sand	Mean change (95% CI)	p-value s-value
Dom FPPA (°)	13.4 ± 3.64	13.5 ± 4.01	−4.50 (−5.48 to −3.52)	−5.79 (−6.80 to −4.79)	1.29 (−0.11 to 2.69)	p = 0.069 S = 3.86
Non-dom FPPA (°)	10.1 ± 3.88	10.9 ± 4.47	−3.48 (−4.34 to − 2.62)	−5.29 (−6.16 to −4.39)	1.80 (0.56 to 3.04)	p = 0.006 S = 7.48
CMJ Height (cm)	21.4 ± 3.31	19.70 ± 3.61	−0.804 (−1.57 to 0.040)	−0.387 (−1.10 to 0.473)	−0.492 (−1.60 to 0.62)	p = 0.376 S = 1.41
10/5 jump RSI (m/s)	1.08 ± 0.22	1.00 ± 0.21	0.074 (−0.005 to 0.153)	0.005 (−0.078 to 0.088)	0.069 (−0.047 to 0.186)	p = 0.235 S = 2.09

0.91 cm) and RSI ($\bar{X} = 0.03$; CI =-0.08 to 0.13 m/s) spanned both positive and negative effect sizes of similar magnitude thus we cannot make clear inferences. Changes in frontal plane projection angle are visualised in Figure 2. Pre-test data for each outcome measure is summarised as mean ± standard deviation for each group and presented in Table 1 alongside the within and between group differences.

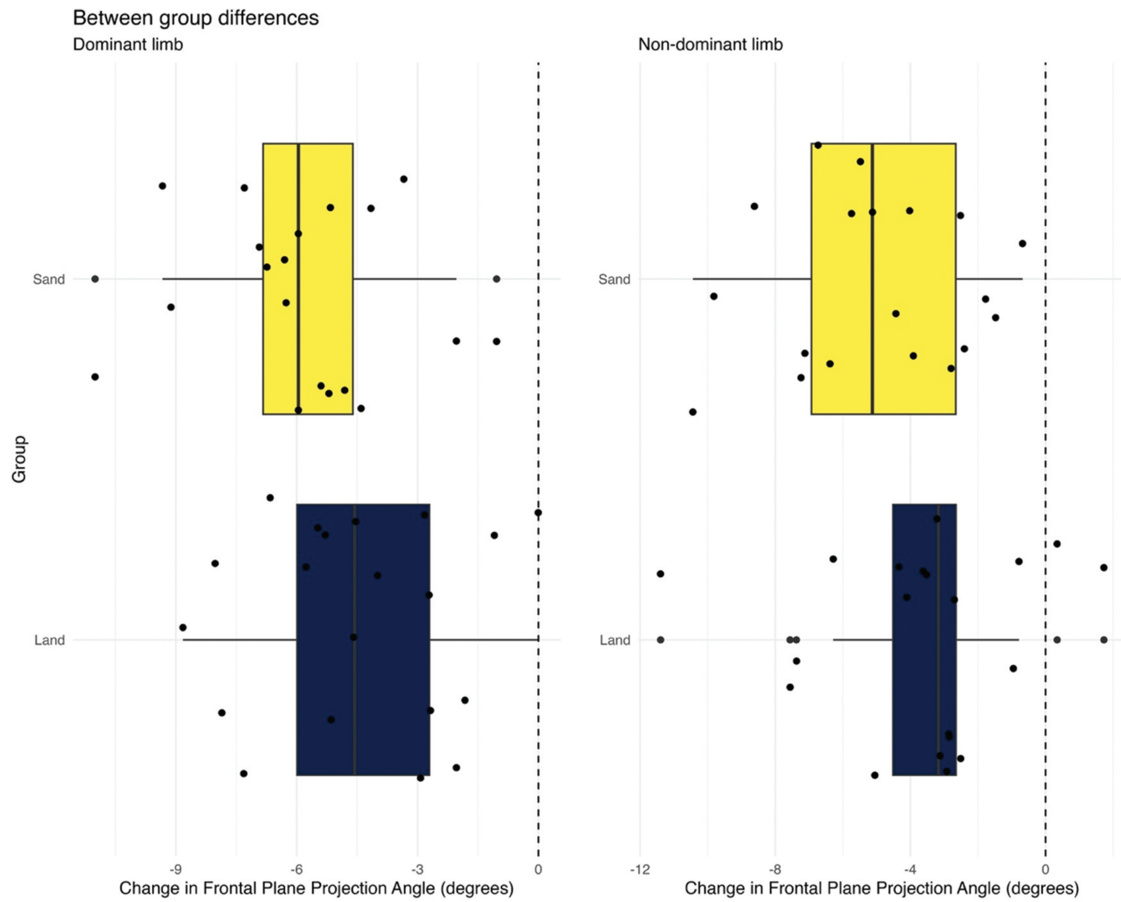

Figure 2. Change in frontal plane projection angle in the SAND and LAND groups for dominant and non-dominant limbs. Boxes represent the median and interquartile range and individual data points are visualised. The grey line denotes the null (zero) hypothesis and negative values (to the left of zero) represent improvement.

Our primary objective was to estimate between-group differences in outcomes (controlled for baseline differences). A greater distribution of effect sizes compatible with the data (and background assumptions) point in the direction of a reduction (i.e. improvement) in FPPA in the SAND group compared to the LAND group. For the dominant limb, effect sizes between −0.11° and 2.69° (95% CI) were highly compatible, with ~ 4 bits of refutational information against the null hypothesis (H_0) (i.e. no more surprising than achieving ~ 4 consecutive heads on a fair sided coin toss). Analysis of compatibility curves (Table 1, Figure 3(a)) shows an effect as large as −2.6° (i.e. reduced FPPA for SAND) had the same P-value as zero effect. For the non-dominant limb, effect sizes between 0.56° and 3.04° (reduced FPPA on SAND) were highly compatible with ~ 7 bits of refutational information against H_0 (i.e. SAND = LAND) (Table 1, Figure 3(b)).

For CMJ, compatible effect sizes lay within our minimal effect size of interest (−1.6 cm to 0.62 cm) (95% CI) with less than 2 bits of information against H_0 (Table 1, Figure 4(a)). Similarly, we observed approximately 2 bits of information against the null hypothesis for RSI. Here analysis of compatibility curves (Table 1, Figure 4(b)) indicates effect sizes of −0.05–0.19 m/s at the 95% compatibility interval.

Discussion

The aim of our study was to investigate the effect of a 6-week jump training intervention (sand- vs. land-based exercise incorporated into warmup) on landing knee valgus (via 2-D FPPA) and jumping performance of adolescent female football players. The main findings were: 1) we observed ~ 4 bits of refutational information (i.e. as surprising as observing 4 consecutive heads on a fair coin toss) against H_o (i.e. SAND is equal to LAND) for differences in FPPA for the dominant limb, suggesting reduced (i.e. favourable) effects in favour of SAND are more compatible than unfavourable effects, 2) approximately 7 bits of refutational information against H_o for the non-dominant limb, thus observing SAND = LAND on the non-dominant limb would be more surprising (3–4 bits) than observing this on the dominant limb, again observed effects for FPPA in favour of SAND are more compatible than unfavourable effects, 3) Comparisons between surfaces for CMJ and RSI yielded less than 2 bits of refutational information against H_o, and effects ranged both negative and positive of similar magnitudes and were within the bounds of smallest worthwhile change, and therefore may not be of practical importance. We provide novel information on the effects of sand-based vs. land-based jump-training on landing knee alignment and jump performance characteristics offering insight into the utility of sand-based intervention strategies for female adolescent footballers.

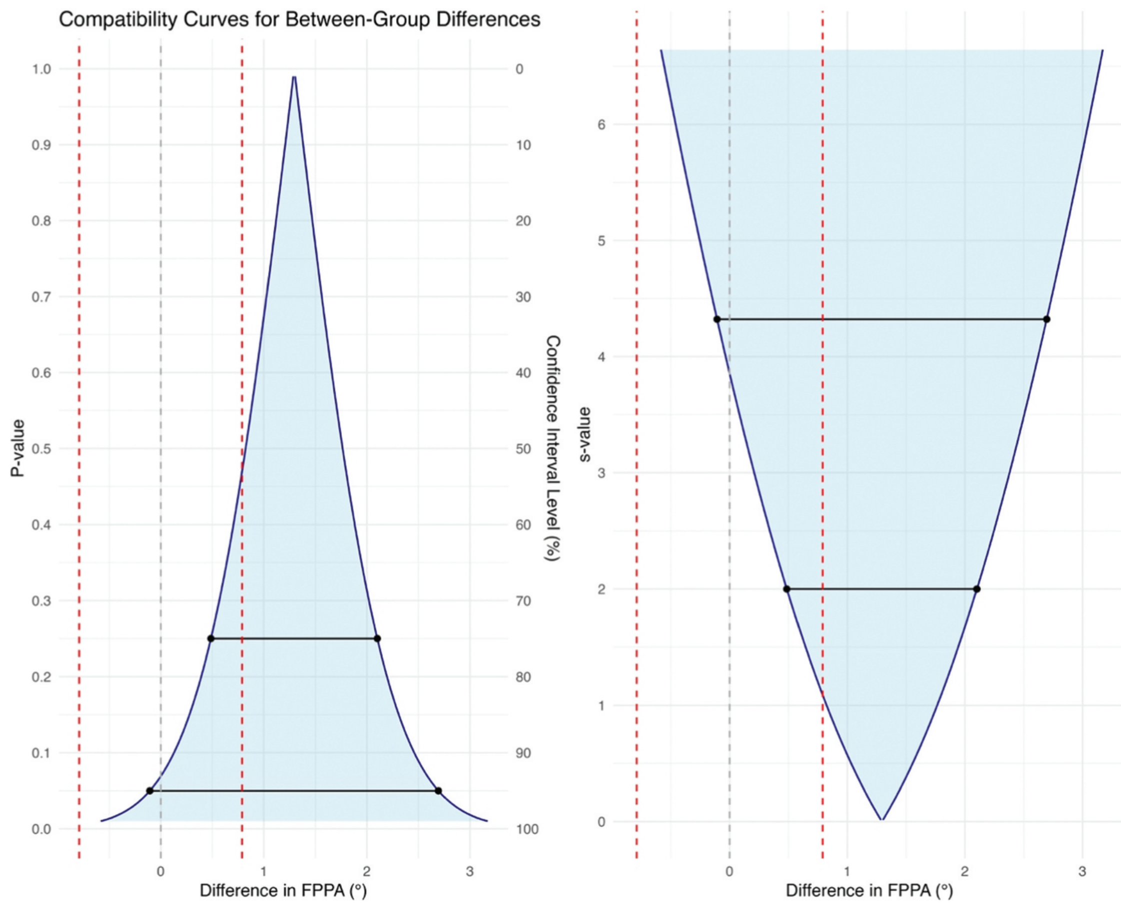

Figure 3a. Shows the *p* value function, and corresponding S- value for frontal plane projection angle in the **dominant limb** (land-sand). Positive values favour sand and negative values favour land. The grey line denotes the null (zero) hypothesis and the red lines the minimally important positive or negative effect size of interest. The horizontal black lines provide the effect sizes for compatibility intervals at 75 and 95% equivalent to s-values of ~ 2 and ~ 4.

Excessive landing knee valgus has been established as a significant risk factor for ACL injury in females (Dingenen et al., 2015; Hewett et al., 2016; Numata et al., 2018; Stuelcken et al., 2016). However, the amount of landing knee valgus which becomes clinically meaningful in terms of increasing ACL injury risk remains unclear along with knowledge on a meaningful reduction on knee valgus in response to an intervention. Herrington and Munro (2010) attempted to establish normative values with respect to knee valgus, using a 2D FPPA method. For a single step landing task, they suggest values of 5° to 12° for females using an active university population, with individuals who demonstrate greater values suggested to be at a higher risk and possibly warrant inclusion in appropriate preventative exercise programmes. The pre-intervention FPPA values in our study for both the dominant (13.4 ± 3.64° – Land; 13.5 ± 4.01° – Sand) and non-dominant limbs (10.1 ± 3.88° – Land; 10.9 ± 4.47° – Sand) were close to or just above the suggested upper limit of 'normal', which could indicate they were a higher risk group. However, normative values for 10–16-year-olds (as with our population) have not yet been established, and a previous study on a younger cohort (13.5 ± 2.14 years) similar to ours, demonstrated baseline values of 17.3 ± 6.2° for a bilateral drop landing task (Colclough et al., 2018). This might suggest higher normative values may be expected in younger cohorts, and indeed may further increase with more advanced landing tasks (i.e. single leg landing task).

Mean FPPA reduced by 4.5° (0.98) and 3.45° (0.89) in the dominant and non-dominant limbs respectively for the LAND group post intervention, with reductions of 5.79° (1.0) and 5.29° (0.9) noted for the SAND group respectively. This ~ 4–6° reduction in FPPA may have brought the females into a 'safer' landing knee valgus on each of the surfaces, if we consider the reported values of Herrington and Munro (2010), with SAND offering a greater beneficial effect. Colclough et al. (2018) using a warmup style jump training programme of 10- to 15-minute duration, demonstrated a 39% reduction in FPPA during a drop landing task, following a 4-week intervention (x3 weekly – 12 sessions). Similarly, Kato et al. (2008) and Herrington (2010) demonstrated 41% and 36% reductions in FPPA respectively during a functional jump shot landing task (12 sessions over 4 weeks). Although we used SLL task and conducted 12 sessions over 6 weeks (rather than 4), we demonstrated similar magnitude reductions in FPPA of 34% (for both dominant and

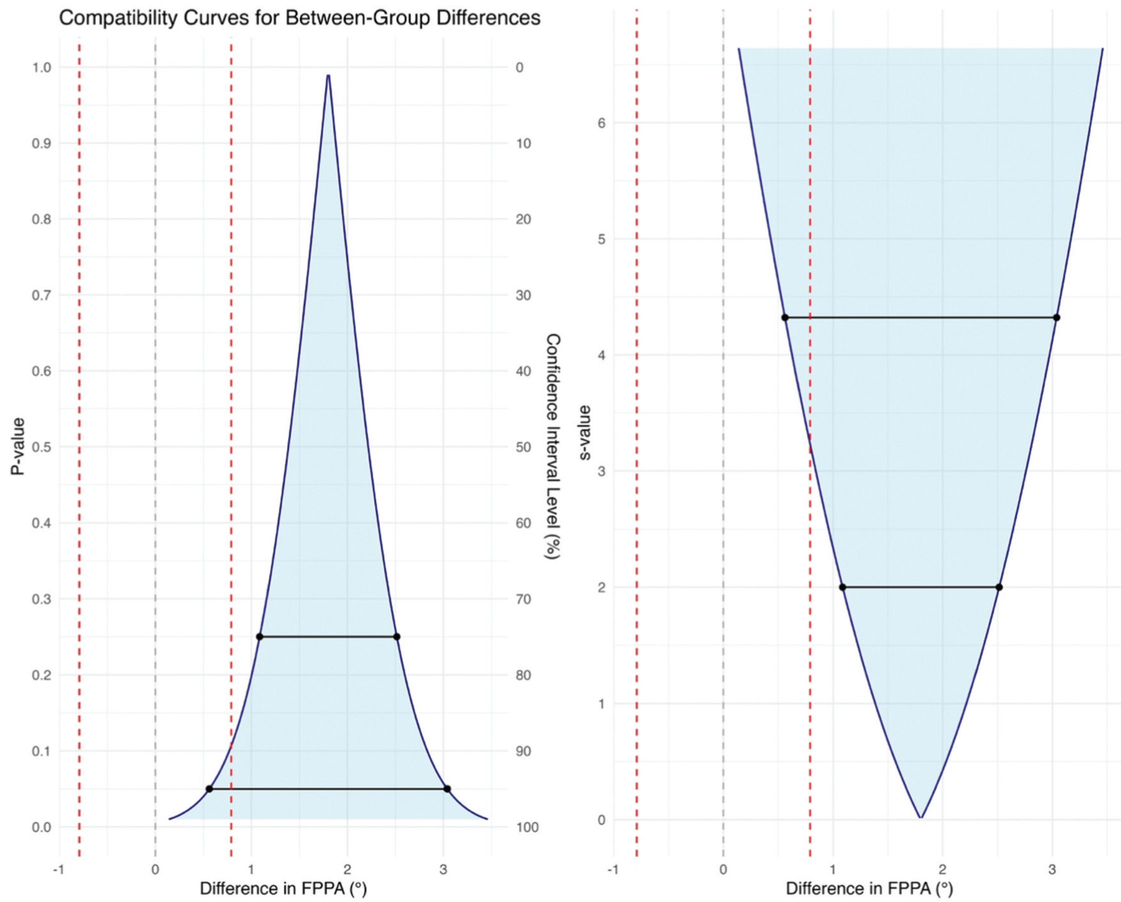

Figure 3b. Shows the *p* value function, and corresponding S- value for frontal plane projection angle in the **non-dominant limb** (land-sand). Positive values favour sand and negative values favour land. The grey line denotes the null (zero) hypothesis and the red lines the minimally important positive or negative effect size of interest. The horizontal black lines provide the effect sizes for compatibility intervals at 75 and 95% equivalent to s-values of ~ 2 and ~ 4.

non-dominant limbs) on LAND, increasing to 43% (dominant limb) and 49% (non-dominant limb) for the SAND group. However, establishing the magnitude of the pre-post changes whilst important was not our primary research question. Except for Kato et al. (2008), these studies (including our own) did not include control groups and thus the effectiveness of the reductions noted may be due to factors beyond the intervention solely, therefore we stress caution when making inferences on the pre-post intervention outcomes.

The distribution of effect sizes for the between group difference (SAND – LAND) in FPPA on landing are mostly compatible with an improvement (i.e. reduction) in knee valgus for both dominant and non-dominant limbs (Figures 3(a,b)) though we observed effects compatible with effects of low practical importance and within the SWC. The observation of a greater distribution of effects sizes compatible with a reduction in FPPA in the SAND compared with LAND group for females, provides some initial information to support the use of a sand surface during jump training (incorporated in a warmup) to reduce landing knee valgus and potentially ACL loading during jumping tasks, which involve a single-leg landing component. Previous authors have suggested that the deformation of sand increases the requirements for dynamic stability upon contact with the surface, when compared to firm ground, and has been demonstrated in walking, running, balance and change of direction tasks (Panebianco et al., 2021; Pinnington et al., 2005; Rafols Parellada et al., 2020; Sebastia-Amat et al., 2020). Increased lower limb muscle activation post landing on sand compared to firm surfaces has been demonstrated during drop jump tasks, across a range of drop heights (30–60 cm) (Peng et al., 2023). Although speculative, it is possible that any increased muscle activation patterns on sand may have helped the female adolescents in the SAND group cope with the unstable nature of the surface, and this could have improved their stability over time, when repeatedly exposed to this surface, and may provide one plausible explanation for the increased magnitude of FPPA reduction noted with this group.

Estimates for pre- to post-intervention jumping performance were generally compatible with a reduction for CMJ and improvement for RSI (Table 1), however the magnitude of the effects could be considered of minimal practical importance. We observed a greater distribution of effects sizes in favour of reduction in between-group differences (Table 1 and Figure 4(a)) for CMJ for SAND vs. LAND however effects were within the bounds of the SWC and there was < 2 bits of information against the null. The distribution of compatible effect sizes for RSI spanned both positive and negative effects of similar magnitude (Figure 4(b)). Again, there was less than

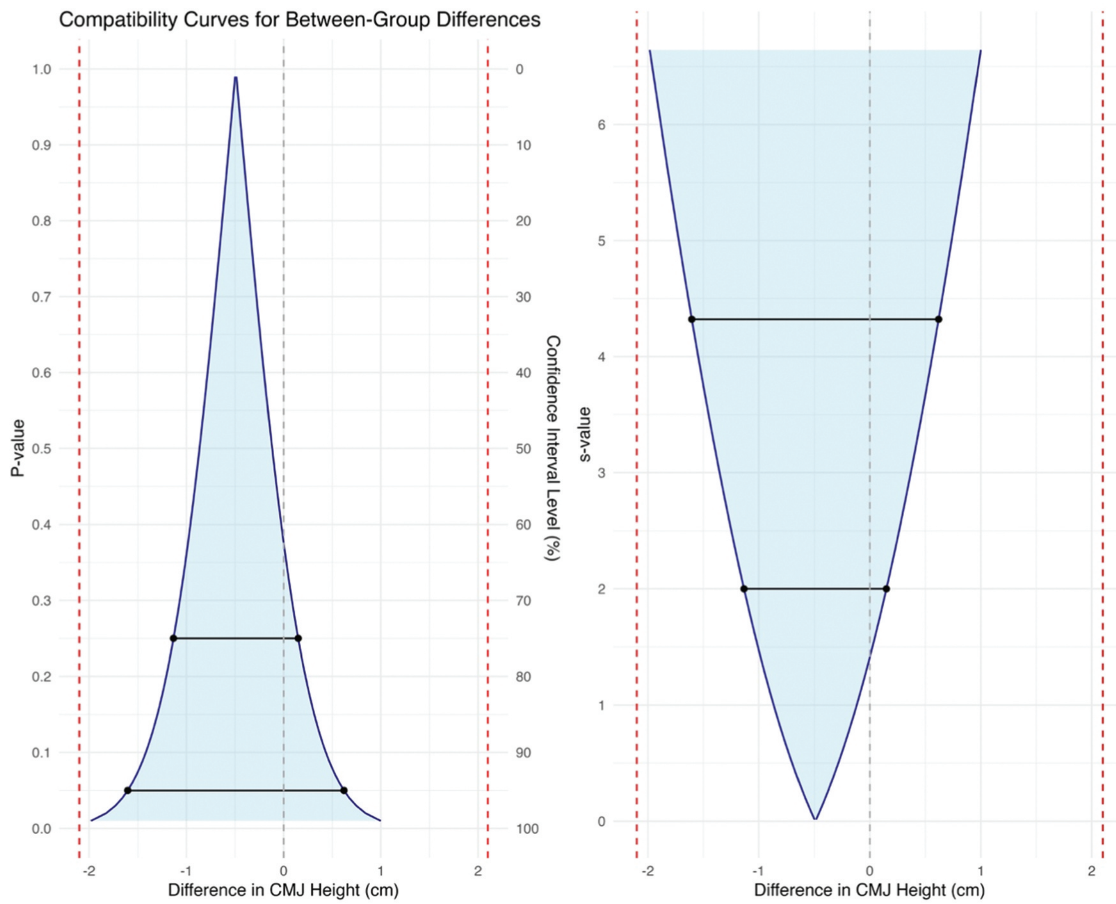

Figure 4a. Shows the *p* value function, and corresponding S- value for countermovement jump height (land-sand). Positive values favour land and negative values favour sand. The grey line denotes the null (zero) hypothesis and the red lines the minimally important positive or negative effect size of interest. The horizontal black lines provide the effect sizes for compatibility intervals at 75 and 95% equivalent to s-values of ~ 2 and ~ 4.

two bits of refutational information against the target hypothesis (SAND = LAND).

Previously Giatsis et al. (2018, 2022) demonstrated (acute study design) reduced jumping performance (jump height) during a drop jump performed on sand compared to land surfaces, with this reduction attributed to the reduced efficiency of the stretch-shortening cycle on the more compliant sand surface. It was proposed that the diminished ground reaction forces on sand (Giatsis et al., 2022) might limit the training specificity needed for firm ground performance (Howatson & Van Someren, 2008), and jump training on a lower impact sand surface, could hinder muscular adaptations. However, the acute responses did not translate into chronic response whereby previous training interventions have demonstrated equivocal improvements in firm ground performance following a 6- to 7-week jump training stimulus (twice weekly) on sand compared to land in several vertical and horizontal jumping tasks, as well as additional balance, agility and sprinting outcomes (Bonavolontà et al., 2021; Hammami et al., 2020; Ozen et al., 2020). Adaptations such as enhanced motor unit recruitment and increased activation of synergists, when training on sand, have been among the proposed mechanisms cited for these performance effects (Arazi et al., 2014). Although there were limited performance effects noted in our study in both the LAND and SAND groups for CMJ and RSI, there appears to be no detriment to performance in these measures (given the effect sizes noted) when using a SAND compared to LAND surface during training.

The specificity of exercises within jump training is known to affect the training response (Coratella et al., 2018). The mechanical demands on the musculoskeletal system are reduced in jump-landing compared to countermovement jump and drop-jump tasks (Ambegaonkar et al., 2011; Arianasab et al., 2017. It may be that the exercises included within our training programme had a greater focus on landing control (jump landing), as opposed to jumping performance and this may in part explain our findings. Furthermore, larger benefits in jumping performance post 6 weeks jump training have been noted previously in more mature females (late teens) compared to pre/early teens (Romero et al., 2021), and thus a reduced scope for larger magnitude improvements in jumping metrics may have been apparent with our cohort. The benefits noted in previous training intervention studies comparing SAND vs LAND were observed following a minimum of 20 minutes of jump training x2 weekly for 6 weeks, and thus our programme (approximately 10 minutes' duration within the warmup) may have provided an insufficient stimulus for jumping performance change across the intervention period on either surface.

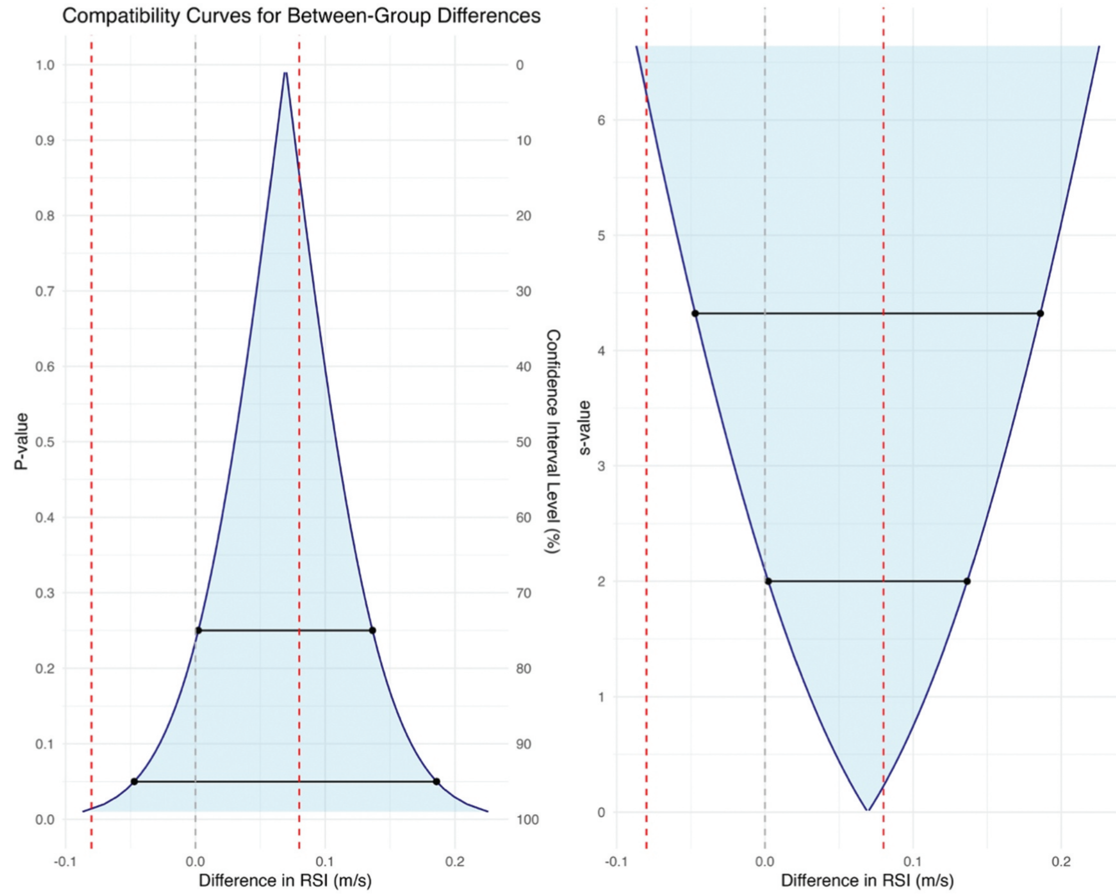

Figure 4b. Shows the *p* value function, and corresponding S- value for reactive strength index (land-sand). Positive values favour land and negative values favour sand. The grey line denotes the null (zero) hypothesis and the red lines the minimally important positive or negative effect size of interest. The horizontal black lines provide the effect sizes for compatibility intervals at 75 and 95% equivalent to s-values of ~ 2 and ~ 4.

Our study is not without limitations. Although the experience level of the young female players, and the training/playing load for each of the groups was similar across the intervention period, this was not directly tracked or controlled for, and thus some of the effects observed may have been a result of differences in these, unrelated to the intervention. We acknowledge that our observations are specific to a healthy young active female football cohort. Our research paves the way for comparisons across pathologic populations to allow wider generalisation. It would also be useful to investigate the longer-term effects of the intervention. The use of 2D FPPA is less sensitive to subtle joint movements such as knee valgus, and possible movement artifact with skin markers can also occur (Copozzo et al., 1996) affecting the accuracy of measurement. However, 2D FPPA is practical to use in an applied setting with greater external validity and has previously been shown to be both a valid and reliable measure of lower-extremity dynamic knee valgus (Comfort et al., 2016; Munro et al., 2012). Furthermore, the intra-rater reliability of the measures in this study was deemed excellent. The magnitude of the differences observed (pre to post intervention) for both the LAND (~3–4°) and SAND groups (~5–6°) is also higher than the standard error of measurement (1.4°) previously reported using this method (Herrington et al., 2017), suggesting these differences are a true reflection of the effects of the conditions. A further limitation of our study was the dropout rate. Although 9 participants were lost to either injury or a lack of adherence during the intervention period, a further 8 participants (with good adherence) were absent during post-intervention testing. This may reflect the challenge of testing with a young population during holiday periods, as well as other parental commitments potentially preventing participation.

Conclusion

Incorporating a sand-based jump- training intervention within a warmup may elicit favourable landing knee alignment changes in asymptomatic adolescent female football players on both dominant and non-dominant limbs with limited evidence of reductions in concomitant jump performance.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [MR], upon reasonable request.

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