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Publication date	2025-09-04
Original Citation	Wu, J. R., O'Flynn, B., Tedesco, S. and Visentin, A. (2025) 'Machine learning model for discriminating Hallux Valgus based on plantar pressure measurements', Gait & Posture, 121, pp.241-242. https://doi.org/10.1016/j.gaitpost.2025.07.259
Type of publication	Article (peer-reviewed);journal-article
Link to publisher's version	10.1016/j.gaitpost.2025.07.259
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Download date	2026-11-17 12:34:05
Item downloaded from	https://hdl.handle.net/10468/18201



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Abstract

Title: Machine Learning Model for Discriminating Hallux Valgus based on Plantar Pressure Measurements

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Introduction
Hallux Valgus (HV) is a foot deformity where the big toe bends outward, causing pain and functional disability in severe cases, impacting quality-of-life. Early diagnosis is essential to prevent complications [1]. Traditional diagnostic methods (visual inspection, radiography, physical examination) are often insufficient for detailed evaluations [2] or costly. This underscores the need for objective reliable diagnostic tools. Deep learning (DL) and machine learning (ML) offer promising alternatives by supporting decision-making.

Research Question
ML/DL application to HV detection remains limited, primarily focusing on radiographs and intrinsic factors (e.g., age, arc height) [3-5]. This study compares ML/DL models to distinguish between individuals with and without HV, using plantar pressure measurements as a non-invasive alternative to radiographs.

Methods
Plantar pressure data from 50 HV pre-surgery patients and 55 healthy individuals were collected using the RSscan Footscan System at 200 Hz [6]. This dataset (CADWALK) contains dynamic measurements from both feet, totalling 4,106 foot images. Statistical features (mean, standard deviation, 25-50-75th percentiles, maximum values) were extracted at specific points (10-30-50-70-90%) across a gait stride. Key gait parameters (walking speed, stride length, time) were also included.

Several ML models were tested: Support Vector Machine (SVM), Random Forest (RF), Logistic Regression (LR), k-Nearest Neighbors (kNN), and Gradient Boosting (GB). A Convolutional Neural Network (CNN) – Table 1 - was applied to raw images from the 50% percentile slice.
Data from same subject were assigned into training, validation, or test sets without overlap. Features were standardized, and images scaled, padded, and augmented (vertical flipping). Models were fine-tuned using grid search and GroupKFold cross-validation. Evaluation metrics included accuracy, precision, recall, and F1-score. ML models were trained using data from individual trials; trial-level predictions were aggregated via majority voting to form an overall prediction at subject-level.

Results
GB outperformed other ML models (F1-score: 0.7881), with GB and RF demonstrating the highest accuracy (87.66% and 87.43%, respectively) - Table 2. Subject-level analysis produced similar results (accuracy: 86.67% - Table 3). CNN achieved 89.41% accuracy on single-image predictions (confusion matrix in Figure).

Discussion
Combining plantar pressure images and gait data proved effective in predicting HV. CNNs performed best, demonstrating the potential of using raw image data for accurate HV identification. This supports the feasibility of using AI for non-invasive HV diagnosis.

Though previous studies [7-8] analyzed this dataset, no ML/DL models were used for HV detection. In [9], the same dataset achieved a classification rate >90%. However, we achieved our results by using data from just five images instead of using all the pressure maps from the full gait stride. More impressively, we reached 89.41% accuracy using just a single image, which is a significant advantage over analyzing the entire pressure map of a full stride as done in [9].

Funding
This publication has emanated from research conducted with the financial support of Taighde Éireann – Research Ireland. Aspects of this work have been supported under the following Grant Numbers: Insight Centre for Data Analytics (12/RC/2289-2), CONNECT Centre for Future Networks and Communications (13/RC/2077), and 16/RC/3918-CONFIRM. All work is cofounded under the European Regional Development Fund. For the purpose of Open Access, the author has applied a CC BY public copyright license to any Author Accepted Manuscript version arising from this submission.

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Layer (type)	Output Shape	Num of Params
sequential_2 (Sequential)	(None, 47, 32, 1)	0
conv2d_3 (Conv2D)	(None, 45, 30, 64)	640
max_pooling2d_3 (MaxPooling2D)	(None, 22, 15, 64)	0
conv2d_4 (Conv2D)	(None, 20, 13, 128)	73,856
max_pooling2d_4 (MaxPooling2D)	(None, 10, 6, 128)	0
conv2d_5 (Conv2D)	(None, 8, 4, 256)	295,168
max_pooling2d_5 (MaxPooling2D)	(None, 4, 2, 256)	0
flatten_1 (Flatten)	(None, 2048)	0
dense_2 (Dense)	(None, 128)	262,272
dropout_1 (Dropout)	(None, 128)	0
dense_3 (Dense)	(None, 1)	129

Table 1 : Summary of the CNN model architecture (single image).

Model	Accuracy	Precision	Recall	F1 Score
SVM	0.8381	0.7838	0.7632	0.7733
RF	0.8476	0.8919	0.7333	0.8049
LR	0.8000	0.6486	0.7500	0.6957
KNN	0.8000	0.6757	0.7353	0.7042
GB	0.8667	0.9459	0.7447	0.8333
NN	0.8429	0.8243	0.7531	0.7871

Table 3: Performance metrics for different models (subject level).

Model	Accuracy	Precision	Recall	F1 Score	Accuracy Variance
SVM	0.8624	0.7532	0.7323	0.7426	0.0026
RF	0.8743	0.8484	0.7228	0.7806	0.0024
LR	0.8463	0.6488	0.7366	0.6899	0.0022
KNN	0.8317	0.6100	0.7104	0.6564	0.0014
GB	0.8766	0.8715	0.7193	0.7881	0.0014
NN	0.8670	0.7763	0.7343	0.7547	0.0023

Table 2: Performance metrics for different models (trial level).

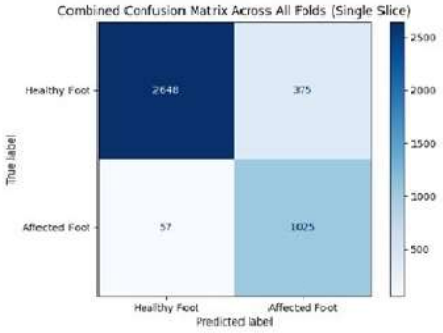


Figure : Confusion matrix across all folds for CNN (single slice)