BMJ Open  Prediction of knee joint pain in Tai Chi practitioners: a cross-sectional machine learning approach

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ABSTRACT

Objective To build a supervised machine learning-based classifier, which can accurately predict whether Tai Chi practitioners may experience knee pain after years of exercise.

Design A prospective approach was used. Data were collected using face-to-face through a self-designed questionnaire.

Setting Single centre in Shanghai, China.

Participants A total of 1750 Tai Chi practitioners with a course of Tai Chi exercise over 5 years were randomly selected.

Measures All participants were measured by a questionnaire survey including personal information, Tai Chi exercise pattern and Irrgang Knee Outcome Survey Activities of Daily Living Scale. The validity of the questionnaire was analysed by logical analysis and test, and the reliability of this questionnaire was mainly tested by a re-test method. The dataset was structured by whether the participant had knee pain, and dataset 2 by whether the participant’s knee pain affected daily living function. Then both datasets were randomly assigned to a training and validating dataset and a test dataset in a ratio of 7:3. Six machine learning algorithms were selected and trained by our dataset. The area under the receiver operating characteristic curve was used to evaluate the performance of the trained models, which determined the best prediction model.

Results A total of 1703 practitioners completed the questionnaire and 47 were eliminated for lack of information. The total reliability of the scale is 0.94 and the KMO (Kaiser-Meyer-Olkin measure of sampling adequacy) value of the scale validity was 0.949 (>0.7). The CatBoost algorithm-based machine learning model achieved the best predictive performance in distinguishing practitioners with different degrees of knee pain after Tai Chi practice. ‘Having knee pain before Tai Chi practice’, ‘knee joint warm-up’ and ‘duration of each exercise’ are the top three factors associated with pain after Tai Chi. The model ‘Having knee pain before Tai Chi practice’, ‘Having Instructor’ and ‘Duration of each exercise’ were most relevant to whether pain interfered with daily life in the model.

Conclusion CatBoost-based machine learning classifier accurately predicts knee pain symptoms after practicing Tai Chi. This study provides an essential reference for practicing Tai Chi scientifically to avoid knee pain.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- The included factors covered most aspects of Tai Chi practice, and their importance in the model was assessed by the SHAPley Additive exPlanations method.
- The Activities of Daily Living Scale has good reliability and validity in evaluating knee function.
- There was no further age stratification, which may affect the results.
- The questionnaire is non-prospective, which may be vulnerable to memory bias.
- The prediction model may be biased when applied to men, as most participants were women.

INTRODUCTION

Tai Chi has become popular worldwide in recent years as a branch of traditional Chinese exercises. It includes several slow and gentle movements such as knee bending, body rotation and arm swinging. Therefore its safety has been well evaluated. Recent studies indicate that Tai Chi improves cardio-pulmonary function and prevents elders from falling. In patients with knee osteoarthritis (KOA), Tai Chi effectively enhances their strength, balance and proprioception, thereby alleviating knee joint stiffness and pain.

A growing body of research on the biomechanics of Tai Chi movements suggests that Tai Chi could improve knee extension strength and balance function, which was more pronounced after more than 8 weeks of exercise. In addition, Tai Chi improves the knee joint’s motor function by changing the way of muscle force recruitment. From the perspective of gait, Tai Chi enhances gait velocity, step length, initial contact angle and maximal angle of flexed knees. It activates both active and antagonistic muscles and enhances coordination and control, resulting in better ankle and knee joint proprioception. Moreover, Tai Chi attenuates...
bone mineral density loss and delays the process of joint degeneration.\textsuperscript{16}

Although Tai Chi improves physical functions, a recent study has shown that Tai Chi exercise may increase the risk of knee pain.\textsuperscript{17} Zhu et al suggested that Tai Chi practice may accompany knee pain related to patellofemoral syndrome.\textsuperscript{18} A study found that Tai Chi practitioners used relatively higher knee muscle activation patterns with greater co-contraction during Tai Chi exercise than normal walking, which may reduce sports injuries but bring knee pain.\textsuperscript{19} Wang et al found that incorrect posture is one of the main factors that directly cause knee injury.\textsuperscript{20} It is considered that several Tai Chi movements are consistent with lunges and pushdowns in which significant peak knee flexion and extension torque can be observed. Thus, practitioners with weak muscle strength in the lower limb who cannot load excessive torque could be prone to injury and pain during Tai Chi exercise.\textsuperscript{21}

Although Tai Chi is popular as an exercise for improving knee function, knee joint pain may also be closely related to a lack of warm-up, wrong movements and knee joint twisting during Tai Chi practice. There is little research on which factors of Tai Chi practice are related to knee pain. It is important to find out what kind of practitioners are likely to have knee pain after years of practice Tai Chi and how severe the knee pain is. If we can use models to solve this problem, more professional advice can be provided for specific practitioners. Machine learning can build models based on past data, make predictions and apply them to the clinic. Some scholars established machine learning-based patients-specific prediction models for KOA to identify and classify KOA patients, which may improve clinical decision-making and precision medicine.\textsuperscript{22}\textsuperscript{23} Bansal et al used surface electromyography data to develop a technique for detecting knee movement sustainability through machine learning.\textsuperscript{24} Tuulpin et al built a model for predicting total knee arthroplasty from ultrasonography through machine learning.\textsuperscript{25} Liu et al established a prediction model for knee pain in middle-aged and older people.\textsuperscript{26} However, the current prediction models for knee joints mainly focus on the gait characteristics or demographic characteristics for predicting the risk factors of KOA or knee joint-related surgery, while few relate to sports risk.

Thus, this research aims to establish machine learning-based models to predict whether Tai Chi practitioners will experience knee joint pain after years of exercise and whether knee pain will affect their activities in daily life. In addition, we used the SHAPley Additive exPlanations (SHAP) method to identify relevant influencing factors for knee pain in the model. Our results can provide scientific guidance for Tai Chi practitioners to avoid the risk of knee pain in the future.

**METHODS**

**Participants**

This study was conducted in cooperation with the Shanghai Tai Chi Association. In this study, we conducted a questionnaire survey of Tai Chi practitioners in Shanghai, China, between April 2015 and December 2016. All participants who had practiced Tai Chi for over 5 years were randomly selected, with the native language of Mandarin that could understand the content of the questionnaire and complete the questionnaire with the help of the investigators.

**Patient and public involvement**

Patients were not involved in developing the research question, study design or selection of outcome measures.

**Questionnaire**

The questionnaire was designed under the guidance of professors from the School of Acupuncture-Moxibustion and Tuina, Shanghai University of Traditional Chinese Medicine. It consisted of two parts: basic information and knee function evaluation. The first part collected the personal information of the participants and their situation in practicing Tai Chi, mainly including the following: participant demographics (gender, age, height, body weight, body mass index (BMI)), years of practice, instructor, exercise frequency, duration of exercise, Tai Chi stance, knee joint warm-up, and previous knee pain. ‘The instructor’ in the questionnaire refers to whether the practitioners have had a professional Tai Chi instructor before. Previous knee pain was to confirm knee pain before practicing Tai Chi. In the second part, the knee joint function of the participants was assessed by the Irrgang Activities of Daily Living Scale, which refers to the questionnaire proposed by Irrgang et al in 1998, including 17 questions, with a total score of 100 points.\textsuperscript{27} The questionnaire should be completed within 15 min. The scale consists of two parts: assessing knee symptoms and the participant’s daily functional limitations. The assessment of daily living function can also reflect the symptoms of the practitioner’s knee joint. The higher the score in this questionnaire, the fewer knee symptoms and the better joint function the practitioner has. Conversely, a lower score indicates that knee symptoms are more severe and by which daily life is seriously affected. Online supplemental files 1 and 2 show the English and Chinese versions of the questionnaire, respectively.

**Procedure**

The subjects of this research were Tai Chi practitioners in some urban areas of Shanghai, including Hongkou District and Minhang District. Before the formal investigation, we trained the investigators to standardize the investigation methods. Then, a preinvestigation was conducted to uncover the problems existing in the questionnaire and the process. We distributed questionnaires in parks and squares where Tai Chi practitioners gather. The questionnaire is issued in paper form and must be filled out and returned on the spot. Questionnaires were issued and collected in the morning as most Tai Chi practitioners tended to practice in the morning. In addition, considering that some elders may need help understanding the questions in the questionnaire, the investigators explained them in detail during the
investigation process. Afterward, the answers to the questionnaire were filled into a file by recorders.

**Machine learning-based modelling**

In this work, we used machine learning technologies to build binary predictive classifiers, distinguishing the following: (1) whether the Tai Chi practitioner has knee pain after years of exercise; (2) if so, whether the practitioner’s knee pain affects daily life. There are four critical steps in our machine learning-based modelling process: data preprocessing, feature selection, algorithm selection and parameter tuning. Finally, we evaluate the resulting models’ prediction performance and choose the best classifier. The workflow is shown in figure 1. The method was also described in our previous study. Scikit-learn, a widely used Python-based machine learning library, was used to train our predictive models (refer to the website: https://scikit-learn.org/stable/).

**Data preprocessing**

For each dataset, we randomly split the entire dataset into a training and validation dataset (70%) and a test dataset (30%). The training and validation dataset was used to train and validate the prediction model, while the test dataset was applied to evaluate the predictive performance of the trained model. A fivefold cross-validation method was used to prepare the training and validation dataset. Fivefold cross-validation can prevent the model from overfitting and is a classic method to evaluate the generalization ability of the training dataset. The training and validation dataset was divided into five subsets with equal sizes at random. One subset was applied to evaluate the model, and the other four subsets were used for training. The cross-validation process was repeated five times, with each of the five subsets used once for validation.

**Feature selection**

We designed many features to reflect the different outcomes of practitioners after years of Tai Chi exercise. Some features use continuous variables: age, height, body weight, BMI and years of practice. The other features with categorical variables were manually selected: gender (male/female), instructor (negative/positive), exercise frequency (every day/5–6 times per week/1–4 times per week/irregular), duration of exercise (<0.5 hours/0.5–1 hour/1–2 hours/>2 hours), Tai Chi stance (high/medium/low/unclear), knee joint warm-up (no warm-up/5 min/10 min/15 min) and previous knee pain (no/occasionally/often). Table 1 shows the statistical details of selected features.

**Algorithm selection and parameter tuning**

To obtain the best prediction model, we selected six representative machine learning algorithms, including Decision Tree, SVM, Logistic Regression, Random
Forest, XGBoost and CatBoost for training, and compared their predictive performance. We need to determine an optimal set of parameters for a selected algorithm. Grid search is applied to go through the parameter space based on the training and validation dataset. We select a finite set for values of each parameter to form the parameter space. Grid search iterates through each parameter combination, for which we evaluate the prediction performance. Finally, the parameters leading to the maximum area under the receiver operating characteristic (ROC) curve (AUC) value are recorded based on the training and validation set.

Model evaluation

AUC value was used to evaluate the performance of the trained models. AUC represents the probability that the model ranks higher in random positive instances than randomly selected negative instances. The value of AUC is between 0 and 1; the higher the AUC value, the better the model distinguishes practitioners with different knee pain outcomes. The final classifier was determined based on the comparison of the predictive performance of each model.

Statistical analysis

Statistical analysis was performed using Python programming software. The numerical variables were represented as means±SD (table 1); categorical variables were described in numbers and percentages. Independent Student’s t-test was used to compare the means of the continuous variables with normal distribution; Welch’s t-test was used if the data were not normally distributed; χ² test was used to compare categorical variables. A p-value less than 0.05 indicates statistically significant. To make the prediction model interpretable, we used the SHAP method to quantify the importance of each feature in the prediction model. SHAP is a representative method to explain the predictions of supervised machine learning-based classifiers. We applied this method to quantify the importance of each feature to the categories of the practitioners (with or without knee pain; knee pain affecting or not affecting daily life). For each feature, we used the metric mean (|SHAP value|), the average value of the absolute values of all the practitioners, to obtain the value of the feature importance. When the |SHAP value| is higher, the feature contributes more to the prediction model.

RESULTS

Tai Chi practitioners

A total of 1750 practitioners filled out the questionnaire and 47 with incomplete information were excluded from the analysis. As a result, 1703 practitioners who had practiced Tai Chi for over 5 years were included for further analysis. 1433 (85.14%) were female, and 270 (15.85%) were male. Participants were aged 26–94, with an average age of 68.58 years (SD=8.72 years). The mean Tai Chi practicing period was 12.54 years (SD=6.33 years). There were 639 practitioners (37.32%) who had never experienced knee pain before practicing Tai Chi, 836 practitioners (49.09%) had knee pain occasionally, and 228 participants (13.39%) often had knee pain. The database comprises 12 features belonging to two categories: five

Table 1  Features of Tai Chi practitioners

<table>
<thead>
<tr>
<th>Feature</th>
<th>n (%)/(mean±SD)</th>
<th>P value (1)</th>
<th>P value (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1433 (85.14%)</td>
<td>0.961</td>
<td>0.817</td>
</tr>
<tr>
<td>Male</td>
<td>270 (15.85%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>68.58±8.72</td>
<td>0.370</td>
<td>0.142</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>162.66±37.04</td>
<td>0.258</td>
<td>0.157</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>61.07±8.99</td>
<td>0.851</td>
<td>0.105</td>
</tr>
<tr>
<td>Body mass index (BMI)</td>
<td>23.26±2.68</td>
<td>0.345</td>
<td>0.377</td>
</tr>
<tr>
<td>Years of Tai Chi practice</td>
<td>12.54±6.33</td>
<td>0.087</td>
<td>0.546</td>
</tr>
<tr>
<td>Have instructor?</td>
<td></td>
<td>0.030*</td>
<td>0.704</td>
</tr>
<tr>
<td>Yes</td>
<td>1163 (68.29%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>540 (31.71%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise frequency</td>
<td></td>
<td>0.333</td>
<td>0.569</td>
</tr>
<tr>
<td>Every day</td>
<td>678 (39.81%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5–6 times/week</td>
<td>361 (21.20%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–4 times/week</td>
<td>277 (16.27%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irregular</td>
<td>387 (22.72%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of each exercise</td>
<td></td>
<td>0.307</td>
<td>0.159</td>
</tr>
<tr>
<td>&lt;0.5 hours</td>
<td>226 (13.27%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5–1 hour</td>
<td>853 (50.09%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–2 hours</td>
<td>558 (32.76%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;2 hours</td>
<td>66 (3.88%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tai Chi stance</td>
<td></td>
<td>0.047*</td>
<td>0.809</td>
</tr>
<tr>
<td>High</td>
<td>404 (23.72%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>709 (41.63%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>410 (24.08%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unclear</td>
<td>180 (10.57%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee joint warm-up</td>
<td></td>
<td>0.001***</td>
<td>0.599</td>
</tr>
<tr>
<td>No warm-up</td>
<td>445 (26.13%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 min</td>
<td>737 (43.28%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>207 (12.16%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 min</td>
<td>314 (18.44%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have knee pain before Tai Chi practice?</td>
<td></td>
<td>&lt;0.001***</td>
<td>&lt;0.001***</td>
</tr>
<tr>
<td>No</td>
<td>639 (37.52%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occasionally</td>
<td>836 (49.09%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Often</td>
<td>228 (13.39%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P value (1): with/without knee pain group; p value (2): does/does not affect daily life group.
*p<0.05 was considered statistically significant; **p<0.01; ***p<0.001.
Reliability and validity of the questionnaire

The validity of the questionnaire was analysed by logical analysis and tests. The score of each dimension of the questionnaire is greater than 0.7, and the total reliability of the questionnaire is 0.94, indicating that it has good reliability and meets the requirements of the questionnaire analysis. The internal consistency reliability of the total questionnaire and each factor score was 0.940 and 0.899–0.907, respectively. The score of each factor is related to the total questionnaire, suggesting that the questionnaire has good structural validity.

The reliability of the questionnaire was mainly tested by the re-test method. Twenty Tai Chi practitioners in Shanghai were randomly selected for re-test, and the interval was 4 weeks from the last test. The reliability coefficient of the test is R=0.87 (p<0.01). The KMO (Kaiser-Meyer-Olkin measure of sampling adequacy) value of the questionnaire validity was 0.949 (>0.7), indicating that the structural validity of the questionnaire is satisfactory.

Use machine learning to predict knee pain after Tai Chi exercise

In our dataset, 643 practitioners (37.76%) had no knee pain after practicing Tai Chi for years (non-knee pain group), while 1060 practitioners (62.24%) experienced knee pain (knee pain group) (dataset 1). In the knee pain group, 902 practitioners’ knee pain did not interfere with their daily life (52.96%). In comparison, 158 practitioners’ knee pain affected their daily life (9.28%) (knee pain affects daily life group vs. knee pain does not affect daily life group, dataset 2). First, we adopted supervised machine learning algorithms to build a binary classifier that distinguished practitioners who had knee pain or not after Tai Chi exercise. Second, we further built a classifier to predict the severity of knee joint symptoms (knee pain affects daily life or not).

To achieve the first goal, six different machine learning algorithms, namely Decision Tree, SVM, Logistic Regression, Random Forest, XGBoost and CatBoost, were selected for training based on dataset 1 (figure 1). The ROC curve of each trained model in predicting knee pain after years of Tai Chi practice. Six different machine learning algorithms, namely Decision Tree, SVM, Logistic Regression, Random Forest, XGBoost and CatBoost, were selected for training. The area under the curve value for each model was presented in the lower right corner of the graph. ROC, receiver operating characteristic.
and 0.895, respectively. The variance of each model is presented in online supplemental table 1. By comparing the predictive performance of these six models, both XGBoost and CatBoost-based models achieved the highest AUC value of 0.895, indicating the best predictive performance in distinguishing practitioners with or without knee pain after Tai Chi exercise.

There are 12 features included in our dataset to drive the classification model, but the importance of each feature in the model is different. Next, we quantified each feature’s SHAP value in the trained CatBoost-based classifier (figure 3). According to the SHAP value of each feature, ‘Have knee pain before Tai Chi practice’ ranked first among all the analyzed features, thus contributing most to distinguishing practitioners with or without knee pain after Tai Chi exercise. The following two important features were ‘Knee joint warm-up’ and ‘Duration of each exercise’ (figure 3).

Next, to visualise the difference between the two groups of participants in dataset 1, we compared the top three features based on the SHAP value in the CatBoost-based classifier. We found that if practitioners did not have knee pain initially, they experienced less knee pain after practicing Tai Chi. However, if they had occasional or frequent knee pain before practicing Tai Chi, knee pain after practice increases. Regarding knee warm-up, warming up for more than 10 min before practicing Tai Chi is less likely to cause knee pain. Likewise, people who exercised for more than an hour were less probably to have knee pain (figure 4).

**Use machine learning to predict further the impact of knee pain on participants’ daily life**

Clinically, we are more concerned about whether practitioners’ knee pain affects daily life. If it affects practitioners’ daily life, they need to adjust their practice.
strategies or seek the help of doctors. Next, we used dataset 2 to train machine learning algorithms to predict further whether practitioners’ daily lives with knee pain would be affected. Dataset two contains two groups; knee pain affects the daily life group, and knee pain does not affect the daily life group as we described before. According to the AUC values, the CatBoost-based classifier (AUC 0.840) can better predict the severity of knee joint symptoms after practicing Tai Chi. See figure 4 for details of all models. The variance of each model is presented in online supplemental table 2.

Then, we used the |SHAP value| to sort the features’ relative importance in the CatBoost-based classifier. The top three features were ‘Have knee pain before Tai Chi practice’, ‘Have Instructor’, and ‘Duration of each exercise’ (figure 5). Our data suggested that the knee joint’s original function significantly influenced the knee function after practicing Tai Chi. Compared with other features, BMI and the height of practitioners contributed less to the classifier.

Finally, we compared the top three features based on the ranking of |SHAP value| in the CatBoost-based classifier to distinguish whether participants’ knee pain affects daily life (figure 6). We found that practitioners who initially had knee pain had a more significant impact on their daily life from Tai Chi practice. Compared with ‘Have knee pain before Tai Chi practice’, ‘Have instructor’, and ‘Duration of each exercise’ have relatively more minor impacts on the daily life of practitioners. However, our analysis also showed that participants with an instructor and more than 30 min of practice had less impact on their daily lives (figure 7).

**DISCUSSION**

This study adopted six machine learning algorithms to predict knee pain and the severity of knee pain after practicing Tai Chi for over 5 years. Based on our results, we conclude the following: (1) CatBoost-based machine learning model achieved the highest AUC value in predicting whether Tai Chi practitioners had knee pain; (2) the feature ‘Have knee pain before Tai Chi practice’ has the most significant dependence to the practitioner category (knee pain/never pain); (3) the CatBoost-based model also offered the best prediction of knee pain severity; (4) the feature ‘Have knee pain before Tai Chi practice’ similarly has the most considerable dependence to the practitioner category (knee pain/affects daily life or not). In short, our models accurately predict Tai Chi practitioners’ knee joint conditions. Our study also demonstrated what factors should be considered to protect the knee joint when practicing Tai Chi.
The US Arthritis Foundation recommends Tai Chi for treating osteoarthritis, while it is still controversial whether Tai Chi exercise affects knee joint function. Scholars believe that Tai Chi relieves stiffness and pain, improves the physical function of KOA patients, and to some extent, reduces analgesic intake.37 38 Li et al established a finite element model by a three-dimensional kinematic analysis of Tai Chi movements. They concluded that practicing Tai Chi may reduce the risk to the knee joint compared with walking and jogging as the intra-articular pressure is less concentrated during Tai Chi practice.39 However, some studies found that knee joint pain might have a close relationship with Tai Chi practice as some Tai Chi movements bring a heavy load inside knee joints.19 Therefore, we designed this study to investigate the correlation between Tai Chi and knee pain using machine learning and built a classification model to predict knee pain after Tai Chi practice.

Different Tai Chi practitioners have different knee joint functions due to their specific conditions. For a particular practitioner, conventional methods cannot tell whether knee joint pain and functional changes will occur after exercise Tai Chi. The research method of artificial intelligence can establish a model by computing existing data to predict the situation of new practitioners after practice. By applying six supervised machine learning-based algorithms and comparing the trained models' prediction performance, our results showed that CatBoost-based models could accurately predict the knee pain symptom (with an AUC value of 0.895) and the severity of knee pain after practicing Tai Chi (with an AUC value of 0.840). CatBoost is an implementation of Gradient

Figure 6  SHAP summary plot of the CatBoost-based classifier in distinguishing whether the daily life of Tai Chi practitioners with knee pain is affected. The relative importance for each feature in the CatBoost-based classifier is obtained by taking the average absolute value of each feature’s SHAP value. SHAP, SHAPley Additive exPlanations.

Figure 7  Comparison of the top three features in distinguishing whether knee pain in Tai Chi practitioners affects daily life based on graph metrics. (A) Knee pain before Tai Chi exercise; (B) have instructor; (C) the duration of each exercise. Blue column: Tai Chi practitioner’s knee pain does not affect daily life; orange column: Tai Chi practitioner’s knee pain affects daily life.
Boosted Decision Trees, which Yandex researchers and engineers developed.\textsuperscript{34} It has been applied in various fields due to its excellent performance for classification and regression tasks.\textsuperscript{40} Besides, we used automatic parameter tuning to achieve the best set of parameters, ensuring our model can achieve the best prediction performance. For a specific practitioner, by collecting the 12 features, our model can calculate whether the practitioner will have knee pain after practicing Tai Chi; if there is knee pain, our model can also judge whether this knee pain can affect their daily life. Therefore, our model can distinguish different situations of knee joint function in Tai Chi practitioners. Our method can provide valuable reference suggestions for specific practitioners, especially for identifying practitioners with knee pain that affects their daily lives. Clinicians can provide valuable advice or prescriptions, slowing the practitioner’s knee joint injury.

Among the 12 features we have selected, it is essential to identify which are more relevant to the classification of practitioners. We have used the SHAP value to sort the importance of these 12 features. ‘Have knee pain before Tai Chi practice’ ranked first in both classification models, indicating that practitioners who had knee pain before Tai Chi practice were susceptible to knee pain after practice. Knee pain has a more significant impact on the daily life of practitioners. This may be related to joint instability caused by pain. Studies have shown that the ratio of leg muscle mass to the whole body is negatively correlated with pain.\textsuperscript{41} The more severe the pain, the weaker the quadriceps muscle strength; exercise will increase the knee joint load and aggravate the pain. Fulton et al.\textsuperscript{27} suggested that post-injury changes were present in strength, proprioception, and kinematics, which may have led to overall motor control and function changes.\textsuperscript{42} Loss of muscle strength and proprioception increases the risk of sports injuries. However, other studies show that Tai Chi can positively affect knee extensor muscle strength, pain, proprioception, and knee function in patients with partial anterior cruciate ligament injuries.\textsuperscript{43} Schmid et al.\textsuperscript{27} found that Tai Chi exercise could improve knee proprioception in people with KOA, improving joint stability and function.\textsuperscript{44} Shen et al.’s study recovered that Tai Chi improves resting-state functional and structural connectivity between the amygdala and medial prefrontal cortex, which is closely associated with chronic pain.\textsuperscript{45} Therefore, further research is needed to explore the influence of post-knee pain on Tai Chi exercise and whether it may enhance the risk of knee joint injury during Tai Chi exercise.

‘Knee joint warm-up’ and ‘Duration of each exercise’ were in the second and third positions in the CatBoost-based classifier in distinguishing whether Tai Chi practitioners have knee pain. Our results suggest that the warm-up and the exercise duration affect the development of knee pain. Figure 4 shows that participants with no warm-up had a high proportion of knee pain, and an introduction of 10–15 min of warm-up can reduce the proportion of knee pain participants. Our result suggested that the shorter the warm-up duration, the higher the risk of knee pain. This result is consistent with previous studies that effective neuro-muscle warm-up strategies could reduce the risk of lower limb injuries during exercise.\textsuperscript{46}

In the present study, we divided the duration of each exercise into four levels, namely <0.5 hours, 0.5–1 hour, 1–2 hours and >2 hours. Among them, the duration of each exercise with the highest proportion was 0.5–1 hour (50.09%), and practicing for more than an hour was less likely to experience knee pain. Studies have shown that Tai Chi can help strengthen lower limb muscles and improve balance. A recent systematic review found that most of the included literature on Tai Chi practice duration ranged from 60 to 90 min.\textsuperscript{47} All these studies have a good effect on improving elders’ lower limb strength and balance ability. However, we cannot rule out the possibility that participants with short exercise duration are due to pre-existing knee pain. Moreover, our study found that whether a practitioner has an instructor also impacts the occurrence of knee pain and knee joint function. Without the guidance of an instructor, self-taught Tai Chi movements can easily be substandard, resulting in changes in the kinematics and biomechanics of the lower limbs. It may increase knee joint contact load, change muscle activation mode, and ultimately affect lower limb function.\textsuperscript{48} Based on the above findings, it is recommended that the warm-up time before practicing should be longer than 10 min, each exercise should be longer than 1 hour, and practicing under the guidance of a professional instructor.

In the next step, we will recruit more Tai Chi practitioners to increase the accuracy of the classifier and build prediction software. The software can automatically predict the outcome of practicing Tai Chi on the knees based on the corresponding indicators, which will help Tai Chi practitioners prevent knee injuries. Therefore, the machine learning-based methods described in this study may become a powerful tool to guide people in practicing Tai Chi scientifically and provide evidence for whether Tai Chi will hurt the knee.

However, our study still has some limitations. First, the practitioners included in the study were all from Shanghai, Tai Chi originated in China, and many Chinese people have learned Tai Chi. Our classifier may not represent all regions of China and other countries. Second, most participants in this study were women (85.14%). Therefore, prediction models may be biased when applied to men. Third, we used a subjective and non-prospective questionnaire and collected those data once with no follow-up, which may be vulnerable to memory bias. In the future, we will include more objective features to quantify conclusions and set up more follow-up time points. Moreover, we focused on knee symptoms rather than a specific disease in this study. In the future, we might pay attention to specific diseases, particularly degenerative joint diseases like KOA. It is expected that our predictive classifier will become more accurate and can be clinically promoted.
CONCLUSION

In this study, we proposed two supervised machine learning-based models to predict whether Tai Chi practitioners would experience knee pain and whether knee pain would affect their daily lives. The CatBoost-based classifiers could predict the outcomes of practitioners well. Furthermore, we use the SHAP method to investigate the feature importance in the models. Having knee pain before Tai Chi practice is the most discriminating factor. In addition, the duration of each exercise, knee joint warm-up, and whether there is an instructor are all crucial factors that affect the practitioner’s knee joint function. Our solution relies on computers and open-source software and is highly accurate. It can quickly identify whether Tai Chi practitioners have knee pain after exercise. The information provided by our classifier is an essential reference to formulate reasonable exercise recommendations for specific practitioners, thereby preventing Tai Chi practitioners from hurting their knees.

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Contributors

LG participated in the study design and data collection. LY participated in data analysis and model building. HX and XS participated in the study design and data collection. YL and YC contributed to the data analysis. YJ, ZK, WS and FY contributed to the data collection. LG is responsible for the study design and data collection. YL and YC contributed to the data analysis. HX and XS participated in the analysis of adverse events in randomized controlled trials. Contemp Clin Trials 2019;82:65–92.

Competing interests

None declared.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication

Not applicable.

Ethics approval

This study involves human participants and was reviewed by the Ethics Committee of Shanghai University of Traditional Chinese Medicine, Yueyang Hospital of Integrated Traditional Chinese Medicine and Western Medicine (No. 2015–034). This was an observational study, and there was no clinical intervention for the participants. Therefore, the study was not registered clinically. All data collected will be used for this study only. The study data were in the form of questionnaires and did not include clinical specimens or human genetic information. All participants were informed and consented before the study. Informed consent includes the study purpose, the content of the study, the security of data and the possible benefits of the study to individuals and society. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review

Not commissioned; externally peer reviewed.

Data availability statement

Data may be obtained from a third party and are not publicly available. The entire dataset and statistical analysis code following receipt of ethics approval are available from LG (yygyongli@shutcm.edu.cn).

Supplemental material

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REFERENCES


A Questionnaire on the Effect of Tai Chi on Knee Health

Dear Tai Chi practitioners:

Osteoarthritis is listed as one of the top three killers of human health by the World Health Organization. Tai chi, which can improve people's physical symptoms, mental health and quality of life, has become a hotspot in world-wide research. Meanwhile, the effect of Tai Chi on knee health grasped the attention of scientists and Tai Chi enthusiasts. Thus, the knee osteoarthritis research team from Yueyang Hospital of Integrated Traditional Chinese and Western Medicine Affiliated to Shanghai University of Traditional Chinese Medicine, together with Shengshiyongnian Tai Chi Association, Tai Chi Association of Minhang District Shanghai, will use questionnaires, internationally recognized assessment scales, and gait analysis to quantitatively evaluate the effects of Tai Chi on knee joint health. Your real opinions on related issues will be of great significance to the promotion of Tai Chi. We sincerely appreciate your help and support in your busy schedule. Thanks!

Part 1
Instructions: Please fill in your real situation on “______”, and choose the options that match your situation and mark as “√”.

1. Name: _______ mobile number: _______ Street and Strict: _________
2. Gender: (1) Male (2) Female Date of Birth: _________
   Height: _______ cm  Weight: _______ kg
3. Start practicing Tai chi from _______ (year)
4. Which Tai Chi style are you currently practicing? (multiple choice)
   (1) Yang Style Tai Chi
   (2) Chen Style Tai Chi
   (3) Wu Style Tai Chi
   (4) Sun Style Tai Chi
   (5) Wu Style Tai Chi
   (6) 24 types of simplified routine, 42 types of competitive routine
   (7) Tai Chi Blade, Tai Chi Sword
   (8) Tai Chi Push-hand, Tai Chi Energizing
   (9) Others: ______
5. Instruction of Tai Chi from:
   (1) Instructor in Community park
   (2) Tai Chi training organized by the school, unit and company
   (3) Tai Chi course of Tai Chi club or fitness club
   (4) Tai Chi masters
   (5) Self-study from teaching video or online
6. Your first Tai chi instructor: ________, your first Tai Chi instructor now: ________.
7. What Tai Chi competitions have you won?
   (1) International level competition
   (2) National level competition
   (3) Provincial and city level competitions
   (4) Others: ______
   (5) not yet obtained
8. Tai Chi exercise frequency:
   (1) Everyday
   (2) 5-7 times a week
   (3) 1-4 times a week
   (4) Irregular
9. Tai Chi exercise duration:
   (1) < 0.5 hour
   (2) 0.5~1 hour
   (3) 1~2 hours
   (4) > 2 hours
10. What is the main motivation for you to keep Tai Chi practicing? (multiple choice)
    (1) I can practise Tai Chi anytime, anywhere.
    (2) Losing weight
    (3) Improving the condition of the skin
    (4) Relieving mood and releasing stress
    (5) Strengthening immunity
    (6) Improving sleep
    (7) Preventing cardiovascular, respiratory, digestive and other diseases
    (8) Enhancing muscle strength, delaying bone and joint degradation
    (9) Making friends, communicating and encouraging each other
    (10) Feeling the cultural heritage of Tai Chi
    (11) Others
11. What is your Tai Chi stance?
    (1) High stance (knee bending 60°-70°)
    (2) Medium stance (knee bending 90°-100°)
    (3) Low stance (knee bending over 100°)
    (4) Unclear
12. Duration of knee joint warm-up exercise before Tai Chi:
    (1) No warm-up
    (2) 5 min
    (3) 10 min
    (4) 15 min
13. Do you have knee pain before Tai Chi practice?
    (1) No
    (2) Occasionally
    (3) Often

———If you chose (3) in question 13, please answer 5 other questions listed below———
   ● Pain occurs in:
     (1) Both knee (2) left knee (3)right knee (4) alternating in both knee
   ● The main location of knee pain is:
     (1) Front of knee (2) Posterior side of knee (3) Lateral side of knee (4) More than 1 location
   ● What are the characteristics of pain?
     (1) Aching pain (2) Prickling pain (3) Swelling pain (4) Others:________
How long does knee pain occur after practice?
(1) 5–15 min  (2) 15–30 min  (3) 30–60 min  (4) over 1 hour

How do you deal with knee pain?
(1) Stop Tai Chi exercise after knee pain
(2) Keep Tai Chi exercise for 1 month and knee pain is relieved
(3) Keep Tai Chi exercise for 3 month and knee pain is relieved
(4) Others:___________

Part 2

Instructions: The following questionnaire is designed to determine the symptoms and limitations that you experience because of your knee while you perform your usual daily activities. Please answer each question by checking the statement that best describes you over the last 1 to 2 days. For a given question, more than one of the statements may describe you, but please mark ONLY the statement that best describes you during your usual daily activities.

Symptoms

1. To what degree does pain in your knee affect your daily activity level?
   _5_ I never have pain in my knee.
   _4_ I have pain in my knee, but it does not affect my daily activity.
   _3_ Pain affects my activity slightly.
   _2_ Pain affects my activity moderately.
   _1_ Pain affects my activity severely.
   _0_ Pain in my knee prevents me from performing all daily activities.

2. To what degree does grinding or grating of your knee affect your daily activity level?
   _5_ I never have grinding or grating in my knee.
   _4_ I have grinding or grating in my knee, but it does not affect my daily activity.
   _3_ Grinding or grating affects my activity slightly.
   _2_ Grinding or grating affects my activity moderately.
   _1_ Grinding or grating affects my activity severely.
   _0_ Grinding or grating in my knee prevents me from performing all daily activities.
3. To what degree does stiffness in your knee affect your daily activity level?

_5_ I never have stiffness in my knee.

_4_ I have stiffness in my knee, but it does not affect my daily activity.

_3_ Stiffness affects my activity slightly.

_2_ Stiffness affects my activity moderately.

_1_ Stiffness affects my activity severely.

_0_ Stiffness in my knee prevents me from performing all daily activities.

4. To what degree does swelling in your knee affect your daily activity level?

_5_ I never have swelling in my knee.

_4_ I have swelling in my knee, but it does not affect my daily activity.

_3_ Swelling affects my activity slightly.

_2_ Swelling affects my activity moderately.

_1_ Swelling affects my activity severely.

_0_ Swelling in my knee prevents me from performing all daily activities.

5. To what degree does slipping of your knee affect your daily activity level?

_5_ I never have slipping of my knee.

_4_ I have slipping of my knee, but it does not affect my daily activity.

_3_ Slipping affects my activity slightly.

_2_ Slipping affects my activity moderately.

_1_ Slipping affects my activity severely.

_0_ Slipping of my knee prevents me from performing all daily activities.

6. To what degree does buckling of your knee affect your daily activity level?

_5_ I never have buckling of my knee.

_4_ I have buckling of my knee, but it does not affect my daily activity.

_3_ Buckling affects my activity slightly.

_2_ Buckling affects my activity moderately.

_1_ Buckling affects my activity severely.

_0_ Buckling of my knee prevents me from performing all daily activities.
3. Buckling affects my activity slightly.

2. Buckling affects my activity moderately.

1. Buckling affects my activity severely.

0. Buckling of my knee prevents me from performing all daily activities.

7. To what degree does weakness or lack of strength of your leg affect your daily activity level?

5. My leg never feels weak.

4. My leg feels weak, but it does not affect my daily activity.

3. Weakness affects my activity slightly.

2. Weakness affects my activity moderately.

1. Weakness affects my activity severely.

0. Weakness of my leg prevents me from performing all daily activities.

Functional Disability with Activities of Daily Living

8. How does your knee affect your ability to walk?

5. My knee does not affect my ability to walk.

4. I have pain in my knee when walking, but it does not affect my ability to walk.

3. My knee prevents me from walking more than 1 mile.

2. My knee prevents me from walking more than 1/2 mile.

1. My knee prevents me from walking more than 1 block.

0. My knee prevents me from walking.

9. Because of your knee, do you walk with crutches or a cane?

3. I can walk without crutches or a cane.

2. My knee causes me to walk with 1 crutch or a cane.

1. My knee causes me to walk with 2 crutches.

0. Because of my knee, I cannot walk even with crutches.
10. Does your knee cause you to limp when you walk?
_2_ I can walk without a limp.
_1_ Sometimes my knee causes me to walk with a limp.
_0_ Because of my knee, I cannot walk without a limp.

11. How does your knee affect your ability to go up stairs?
_5_ My knee does not affect my ability to go up stairs.
_4_ I have pain in my knee when going up stairs, but it does not limit my ability to go up stairs.
_3_ I am able to go up stairs normally, but I need to rely on use of a railing.
_2_ I am able to go up stairs one step at a time with use of a railing.
_1_ I have to use crutches or a cane to go up stairs.
_0_ I cannot go up stairs.

12. How does your knee affect your ability to go down stairs?
_5_ My knee does not affect my ability to go down stairs.
_4_ I have pain in my knee when going down stairs, but it does not limit my ability to go down stairs.
_3_ I am able to go down stairs normally, but I need to rely on use of a railing.
_2_ I am able to go down stairs one step at a time with use of a railing.
_1_ I have to use crutches or a cane to go down stairs.
_0_ I cannot go down stairs.

13. How does your knee affect your ability to stand?
_5_ My knee does not affect my ability to stand. I can stand for unlimited amounts of time.
_4_ I have pain in my knee when standing, but it does not limit my ability to stand.
_3_ Because of my knee I cannot stand for more than 1 hour.
_2_ Because of my knee I cannot stand for more than 1/2 hour.
<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Because of my knee I cannot stand for more than 10 minutes.</td>
<td>1</td>
</tr>
<tr>
<td>I cannot stand because of my knee.</td>
<td>0</td>
</tr>
<tr>
<td>How does your knee affect your ability to kneel on the front of your knee?</td>
<td></td>
</tr>
<tr>
<td>My knee does not affect my ability to kneel on the front of my knee.</td>
<td>5</td>
</tr>
<tr>
<td>I have pain when kneeling on the front of my knee, but it does not limit my ability to kneel.</td>
<td>4</td>
</tr>
<tr>
<td>I cannot kneel on the front of my knee for more than 1 hour.</td>
<td>3</td>
</tr>
<tr>
<td>I cannot kneel on the front of my knee for more than 1/2 hour.</td>
<td>2</td>
</tr>
<tr>
<td>I cannot kneel on the front of my knee for more than 10 minutes.</td>
<td>1</td>
</tr>
<tr>
<td>I cannot kneel on the front of my knee.</td>
<td>0</td>
</tr>
<tr>
<td>How does your knee affect your ability to squat?</td>
<td></td>
</tr>
<tr>
<td>My knee does not affect my ability to squat. I can squat all the way down.</td>
<td>5</td>
</tr>
<tr>
<td>I have pain when squatting, but I can still squat all the way down.</td>
<td>4</td>
</tr>
<tr>
<td>I cannot squat more than 3/4 of the way down.</td>
<td>3</td>
</tr>
<tr>
<td>I cannot squat more than 1/2 of the way down.</td>
<td>2</td>
</tr>
<tr>
<td>I cannot squat more than 1/4 of the way down.</td>
<td>1</td>
</tr>
<tr>
<td>I cannot squat at all.</td>
<td>0</td>
</tr>
<tr>
<td>How does your knee affect your ability to sit with your knee bent?</td>
<td></td>
</tr>
<tr>
<td>My knee does not affect my ability to sit with my knee bent. I can sit for unlimited amounts of time.</td>
<td>5</td>
</tr>
<tr>
<td>I have pain when sitting with my knee bent, but it does not limit my ability to sit.</td>
<td>4</td>
</tr>
<tr>
<td>I cannot sit with my knee bent for more than 1 hour.</td>
<td>3</td>
</tr>
<tr>
<td>I cannot sit with my knee bent for more than 1/2 hour.</td>
<td>2</td>
</tr>
<tr>
<td>I cannot sit with my knee bent for more than 10 minutes.</td>
<td>1</td>
</tr>
<tr>
<td>I cannot sit with my knee bent.</td>
<td>0</td>
</tr>
</tbody>
</table>
17. How does your knee affect your ability to rise from a chair?

_5_ My knee does not affect my ability to rise from a chair.

_4_ I have pain when rising from the seated position, but it does not affect my ability to rise from the seated position.

_2_ Because of my knee I can only rise from a chair if I use my hands and arms to assist.

_0_ Because of my knee I cannot rise from a chair.
尊敬的太极拳爱好者：您好！

骨关节炎被世界卫生组织列为危害人类健康的三大杀手之一。太极拳能改善人们躯体症状、心理健康，提高生活质量，已成为全球研究热点，而围绕习练太极拳对膝骨关节健康的影响，正成为科学家和广大太极拳爱好者关注的焦点。因此，上海中医药大学附属岳阳中西医结合医院膝骨关节炎研究团队、盛世永年太极、上海市闵行区太极拳协会，采用调查问卷、国际公认的评估量表、膝关节步态分析等方法，客观量化评价太极拳对膝骨关节功能的影响。

您对相关问题的真实意见表达，将对太极的弘扬推广具有重要的意义！恳请您在百忙之中给予帮助和支持，在此真诚地表达对您的由衷感谢！

第一部分
填表说明：请在“□”上，填与您的真实情况；请在符合您情况的选项上划“√”。

1. 姓名：________手机号：__________所在街镇：__________
2. 您的性别：（1）男（2）女；出生年月：_____年____月；
3. 身高：_____cm，体重：___公斤
4. 您开始习练太极拳的时间：年
5. 您目前主要锻炼的太极套路（可多选）：
   (1) 杨式太极拳
   (2) 陈式太极拳
   (3) 吴式太极拳
   (4) 孙式太极拳
   (5) 武式太极拳
   (6) 24式简化套路、42式竞赛套路
   (7) 太极刀、太极剑
   (8) 太极推手、发劲
   (9) 其他：________
6. 您学习太极拳的主要来源：
   (1) 社区公园里有太极老师教
   (2) 所在学校、单位、公司组织的太极拳培训
   (3) 报名参加太极会所、健身会所的太极拳课程
   (4) 正式向太极名家拜师学艺
   (5) 从教学光碟或者网上自学
7. 您获得过哪些太极拳比赛的好成绩：
   (1) 国际级比赛
   (2) 全国级比赛
   (3) 省市级比赛
   (4) 其它________
   (5) 尚未获得
8. 您太极拳锻炼的频率：
   (1) 每天至少1次
   (2) 每周5-7次
   (3) 每周1-4次

不定期锻炼

9. 您太极拳锻炼每次持续的时间：
(1) 小于半小时
(2) 半小时-1小时
(3) 1小时-2小时
(4) 2小时以上

10. 您能够坚持太极拳锻炼的主要动力是什么？(可多选)
(1) 能随时随地锻炼
(2) 能够减肥
(3) 让皮肤变得更好
(4) 能舒缓情绪、释放压力
(5) 提高免疫力
(6) 改善睡眠
(7) 防治心血管、呼吸系统、消化系统等疾病
(8) 增强肌肉力量，有效缓解骨骼、关节退化
(9) 结识各界拳友同修，相互交流和彼此鼓励
(10) 能逐步体悟太极的深厚文化底蕴
(11) 其它

11. 您锻炼太极拳的架式高低：
(1) 高架，膝盖屈膝 60-70°
(2) 中等，膝盖屈膝 90-100°
(3) 低架，膝盖屈膝大于 100°
(4) 不清楚

12. 您太极拳锻炼前会做膝关节的热身运动吗？
(1) 不做热身运动
(2) 约 5 分钟
(3) 约 10 分钟
(4) 15 分钟以上

13. 您在大极拳锻炼过程中出现过膝盖疼痛吗？
(1) 没有
(2) 偶尔
(3) 经常
——如第 13 题选(3)，请回答如下 5 个问题——
● 膝盖疼痛出现在：
  (1) 双膝都有
  (2) 左膝
  (3) 右膝
  (4) 双膝交替
● 膝盖疼痛的主要位置是：
  (1) 膝前面
  (2) 膝后面
  (3) 膝侧面
  (4) 两个位置及以上
● 您在膝盖疼痛时，会出现什么样的疼痛？
  (1) 酸痛
  (2) 刺痛
  (3) 胀痛
  (4) 其他
  (5) 您一般每次在练拳多长时间后出现膝盖疼痛？
  (1) 5—15 分钟
  (2) 15—30 分钟
  (3) 30-60 分钟
  (4) 1 个小时之后
● 膝盖出现疼痛，您如何应对？
  (1) 膝盖出现疼痛后，不再进行太极拳锻炼
  (2) 膝盖出现疼痛，坚持太极拳锻炼 1 个月左右，膝痛得到缓解或消失
  (3) 膝盖出现疼痛，坚持太极拳锻炼 3 个月左右，膝痛得到缓解或消失
  (4) 其他
第二部分

填表说明：下列问题用来调查您在日常生活中的膝部状况。请回答每一个问题，核实最适合您近1-2天的描述。每一个问题可能有多个答案，但请“√”标明最符合您日常活动的那一个。

1. 您膝部的疼痛影响日常生活水平到什么程度？
   (1) 我膝部从不疼痛。
   (2) 我膝部痛，但不影响我的日常生活。
   (3) 疼痛轻度影响我的日常生活。
   (4) 疼痛中度影响我的日常生活。
   (5) 疼痛严重影响我的日常生活。
   (6) 我膝部的疼痛使我不能从事所有的日常活动。

2. 您膝部的摩擦影响日常生活水平到什么程度？
   (1) 我膝部从不摩擦。
   (2) 我膝部有摩擦，但不影响我的日常生活。
   (3) 摩擦轻度影响我的日常生活。
   (4) 摩擦中度影响我的日常生活。
   (5) 摩擦严重影响我的日常生活。
   (6) 我膝部的摩擦使我不能从事所有的日常活动。

3. 您膝部的僵硬影响日常生活水平到什么程度？
   (1) 我膝部从不僵硬。
   (2) 我膝部有僵硬，但不影响我的日常生活。
   (3) 僵硬轻度影响我的日常生活。
   (4) 僵硬中度影响我的日常生活。
   (5) 僵硬严重影响我的日常生活。
   (6) 我膝部的僵硬使我不能从事所有的日常活动。

4. 您膝部的肿胀影响日常生活水平到什么程度？
   (1) 我膝部从不肿胀。
   (2) 我膝部有肿胀，但不影响我的日常生活。
   (3) 肿胀轻度影响我的日常生活。
   (4) 肿胀中度影响我的日常生活。
   (5) 肿胀严重影响我的日常生活。
   (6) 我膝部的肿胀使我不能从事所有的日常活动。

5. 您膝部的滑动影响日常生活水平到什么程度？
   (1) 我膝部从不滑动。
   (2) 我膝部有滑动，但不影响我的日常生活。
   (3) 滑动轻度影响我的日常生活。
   (4) 滑动中度影响我的日常生活。
   (5) 滑动严重影响我的日常生活。
   (6) 我膝部的滑动使我不能从事所有的日常活动。

6. 您膝部绞锁（膝关节突然被卡住，不能伸屈）影响日常生活水平到什么程度？
   (1) 我膝部从不绞锁。
   (2) 我膝部有绞锁，但不影响我的日常生活。
   (3) 绞锁轻度影响我的日常生活。
   (4) 绞锁中度影响我的日常生活。
5. 绞锁严重影响我的日常活动。
6. 我膝部的绞锁使我不能从事所有的日常活动。 

7. 您腿部无力影响日常活动水平到什么程度？
(1) 我腿部从没感到无力。
(2) 我腿部感到无力，但不影响我的日常活动。
(3) 无力轻度影响我的日常活动。
(4) 无力中度影响我的日常活动。
(5) 无力严重影响我的日常活动。
(6) 我腿部的无力使我不能从事所有的日常活动。

8. 你的膝部对您的行走能力影响有多大？
(1) 我的膝部对我的行走能力没有影响。
(2) 我行走时膝部有疼痛，但不影响我的行走能力。
(3) 我的膝部使我行走不能超过 1.6 公里。
(4) 我的膝部使我行走不能超过 800 米。
(5) 我的膝部使我行走不能超过 300 米。
(6) 我的膝部使我不能行走。

9. 因为您的膝部，你行走用双拐或单手杖吗？
(1) 我可以不用拐杖行走。
(2) 有时候，我的膝部使我需用单拐或单手杖行走。
(3) 我的膝部使我需用双拐行走。
(4) 因为膝部，我即使用拐也不能行走。

10. 你行走时，膝部会导致您跛行吗？
(1) 我可以行走，而没有跛行。
(2) 有时候，我的膝部使我行走时跛行。
(3) 因为膝部，我不跛就不能行走。

11. 您的膝部对您的上楼能力影响有多大？
(1) 我的膝部对我的上楼能力没有影响。
(2) 我上楼时膝部有疼痛，但不影响我的行走能力。
(3) 我能正常上楼，但需要依靠使用扶手。
(4) 我能使用扶手，一步一步地上楼。
(5) 我必须使用双拐或单手杖上楼。
(6) 我不能上楼。

12. 您的膝部对您的下楼能力影响有多大？
(1) 我的膝部对我的下楼能力没有影响。
(2) 我下楼时膝部有疼痛，但不影响我的行走能力。
(3) 我能正常下楼，但需要依靠使用扶手。
(4) 我能使用扶手，一步一步地下楼。
(5) 我必须使用双拐或单手杖下楼。
(6) 我不能下楼。

13. 您的膝部对您的站立能力影响有多大？
(1) 我的膝部对我的站立能力没有影响，我可以没有时间限制的站立。
(2) 我站立时膝部有疼痛，但不影响我的行走能力。
(3) 我的膝部使我站立不能超过 1 小时。
(4) 我的膝部使我站立不能超过 0.5 小时。
14. 您的膝部对您前跪的能力影响有多大？
(1) 我的膝部对我的前跪能力没有影响，我可以没有时间限制的前路。
(2) 我前跪时膝部有疼痛，但不影响我的前跪能力。
(3) 我的膝部使我前路不能超过 1 小时。
(4) 我的膝部使我前路不能超过 0.5 小时。
(5) 我的膝部使我前路不能超过 10 分钟。
(6) 我的膝部使我不能前跪。

15. 您的膝部对您蹲下的能力影响有多大？
(1) 我的膝部对我的蹲下能力没有影响，我可以完全蹲下。
(2) 我蹲下时膝部有疼痛，但我能完全蹲下。
(3) 我蹲下不能超过 3/4。
(4) 我蹲下不能超过 1/2。
(5) 我蹲下不能超过 1/4。
(6) 我根本不能蹲下。

16. 您的膝部对您屈膝坐立的能力影响有多大？
(1) 我的膝部对我屈膝坐立的能力没有影响，我可以没有时间限制的坐着。
(2) 我屈膝坐着时膝部有疼痛，但不影响我的坐立能力。
(3) 我的膝部使我屈膝坐立不能超过一小时。
(4) 我的膝部使我屈膝坐立不能超过半小时。
(5) 我的膝部使我屈膝坐立不能超过 10 分钟。
(6) 我的膝部使我不能屈膝坐立。

17. 您的膝部对您从椅子上站起的能力影响有多大？
(1) 我的膝部对我从椅子站起的能力没有影响。
(2) 我从坐位站起时有疼痛，但不影响我从坐位站起的能力。
(3) 因为膝部，我只能依靠手臂的帮助从椅子上站起。
(4) 因为膝部，我不能从椅子上站起。
**Suppl. table 1 Mean and variance of each model in predicting knee pain after Tai Chi exercises.**

<table>
<thead>
<tr>
<th>model</th>
<th>mean</th>
<th>variance</th>
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</thead>
<tbody>
<tr>
<td>CatBoost</td>
<td>0.892</td>
<td>9.48E-07</td>
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<tr>
<td>XGBoost</td>
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<td>1.51E-06</td>
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<tr>
<td>Random Forest</td>
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<td>5.28E-05</td>
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<tr>
<td>Logistic Regression</td>
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<td>0</td>
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<tr>
<td>SVM</td>
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<td>0</td>
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<tr>
<td>Decision Tree</td>
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<td>1.51E-02</td>
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</table>

**Suppl. table 2 Mean and variance of each model in predicting whether the daily life of Tai Chi practitioners with knee pain will be affected.**

<table>
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<th>model</th>
<th>mean</th>
<th>variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CatBoost</td>
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<td>7.11E-05</td>
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<td>XGBoost</td>
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<td>0</td>
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<tr>
<td>SVM</td>
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<td>0</td>
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<tr>
<td>Decision Tree</td>
<td>0.732</td>
<td>4.67E-03</td>
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</tbody>
</table>