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Patient Rank-based Curriculum Learning for Predicting Functional Outcome in Stroke after Thrombectomy

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Background and aims: Functional outcome is heterogeneous after acute ischemic stroke (AIS). In the present study, we aimed to predict functional outcome from MRI imaging data (without clinical variables) using a machine learning algorithm in AIS patients.

Methods: HIBISCUS-STROKE cohort enrolled patients admitted in the Lyon Stroke Center for anterior circulation AIS due to large vessel occlusion treated with mechanical thrombectomy following MRI. Modified rankin scale (mRS) was assessed at 3 months during a face to face visit. From total of 119 patients, 34% had mRS≤2 (Fig.1).

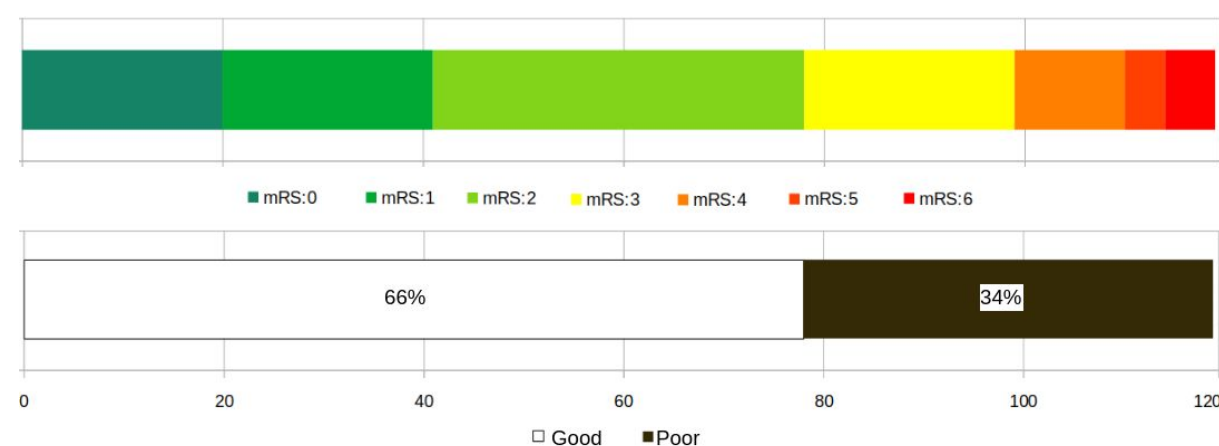


Fig. 1. Top) Distribution of the 3-month modified rankin scale (mRS) scores, bottom) associated binarization into good (mRS≤2) and poor (mRS>2) outcomes.

We proposed a multi-modal Convolutional Neural Network-Long Short-Term Memory (CNN-LSTM) for processing five image modules, i.e. Apparent Diffusion Coefficient (ADC), Cerebral Blood Flow (CBF), Cerebral Blood Volume (CBV), Diffusion-Weighted-Imaging (DWI) and Time to maximum (Tmax). We applied a curriculum learning, a class of learning in which first starts with only “easy” patients (from the model's perspective) and then gradually includes more difficult patients. The training has two main steps: first a CNN-LSTM ranks the patients from 1 to 10 based on their “easiness” (Fig.2), and then another CNN-LSTM (similar architecture) uses the rank information to gradually learn the mRS scores by including different ranked patients at different learning stages (Fig.3). A patient was considered as easy if the model predicted its mRS score correctly 10 out of 10 during the 10-fold cross-validation.

Table 1. Performance of the proposed patient rank-based curriculum learning compared to the standard CNN-LSTM model.

Model	AUC	MAE	Accuracy	Specificity	Sensitivity	F1-score
Standard CNN-LSTM	0.62±0.04	0.42±0.01	0.63±0.04	0.61±0.04	0.61±0.04	0.60±0.03
Proposed Curriculum Learning CNN-LSTM	0.68±0.05	0.38±0.01	0.69±0.02	0.65±0.03	0.66±0.03	0.64±0.02

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References. CNN-LSTM Based Multimodal MRI and Clinical Data Fusion for Predicting Functional Outcome in Stroke Patients, N. Hatami et al., EMBC 2022.

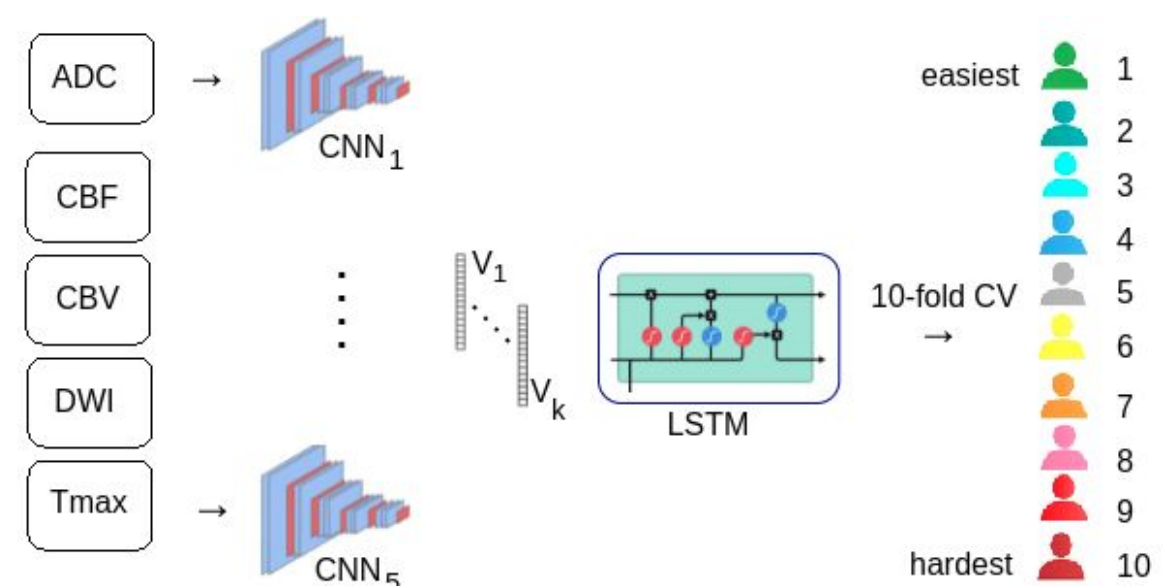


Fig. 2. Identification of the “easy” and “hard” patients using Ranker Network.

Six different measures were used to evaluate the performance of the models: classification accuracy, F1 score, sensitivity, specificity, Mean-Absolute-Error (MAE) and Area Under the Curve (AUC). Performance (mean±standard deviation over 10 runs) of the proposed patient rank-based curriculum learning is compared to the standard CNN-LSTM model.

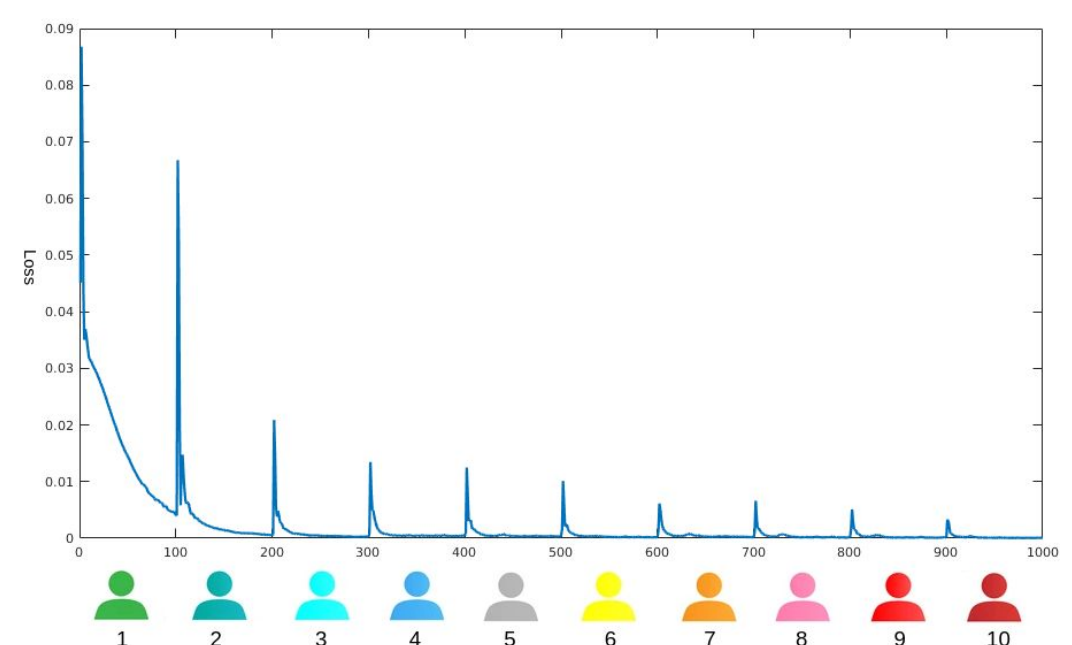


Fig. 3. Learning curve of the CNN-LSTM using rank-based curriculum learning. It first starts with only easy patients and then gradually increases the task difficulty.

Results: As shown in Table 1, the performance of the proposed patient rank-based curriculum learning outperforms the standard CNN-LSTM model with the similar architecture and parameters.

Conclusions: Inspired by the learning order in human curricula, we proposed a curriculum learning for CNN-LSTM for predicting functional outcome in AIS patients. Experimental results demonstrate the benefit of gradual increase of the difficult patients during the network training.