Automated analysis of Parkinson's Disease on the basis of evaluation of handwriting

Bachelor's Thesis in Computer Science

submitted
by

Michael Kupfer

born 04.03.1999 in 91353 Hausen

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Lehrstuhl für Mustererkennung (Informatik 5)
Department Informatik
Friedrich-Alexander-Universität Erlangen-Nürnberg.

Advisor: M. Sc. Juan Camilo Vasquez Correa, Prof. Dr. Ing. Habil- Elmar Nöth.

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Erlangen, den 27th September 2020

Übersicht

In dieser These werden derzeitig moderne Methoden zur automatisierten Analyse von Parkinson zusammen mit neuen Ideen im Bereich der Signalverarbeitung getestet. Da es zur Zeit keine Heilung für Parkinson gibt, ist es wichtig Methoden zur automatischen Überwachung und Analyse einzuführen. Dazu wurden Handschriftproben von 49 Kontrollpersonen und 75 Parkinsonpatienten benutzt, welche durch ein Graphik-Tablet erhalten wurden. Die Testpersonen führten verschiedene Zeichenaufgaben durch. Mit einer kinematischen Analyse werden Genauigkeiten von bis zu 77% erreicht, wenn eine Aufgabe alleine benutzt wird und Genauigkeiten von bis zu 86% werden erreicht, wenn man mehrere Aufgaben kombiniert. Eine neu entwickelte Spectralanalyse erzielt Ergebnisse von bis zu 96% für eine individuelle Aufgabe. Das Kombinieren der Spectralfeatures einer alleinstehenden Aufgabe mit Features einer anderen Aufgabe oder von einer anderen Art der Analyse führt zu keiner Verbesserung der Ergebnisse. Die Vorhersage der Schwere der Krankheit anhand der Features des Zwei-Klassen-Problems war nicht möglich. Ein Versuch wurde unternommen, das Geschwindigkeitsprofil eines Striches durch logarithmische Normalverteilungen zu modellieren und die dadurch erhaltenen Parameter zur Klassifizierung zu nutzen. Aufgrund von Schwierigkeiten bei der Modellierung von Strichen unterschiedlicher Länge schlug die Klassifizierung fehl.

Abstract

In this thesis current state-of-the-art methods of automatic analysis of Parkinson's disease (PD) are tested along with new ideas of signal processing. Since there is currently no cure for PD, it is important to introduce methods for automatic monitoring and analysis. Therefore handwriting-samples of 49 healthy subjects and 75 PD patients acquired with a graphic tablet are used. Those subjects performed different drawing tasks. With a kinematic analysis accuracies of up 77% are achieved when using one task alone and accuracies up to 86% are achieved when combining different tasks. A newly developed spectral analysis resulted in scores of up to 96% for an individual task. Combining the spectral features of a standalone task with features from different tasks or a different analysis did not lead to better results. Making predictions about the severity of the disease based on the features acquired for the bi-class problem failed. An attempt was made modeling the velocity profile of strokes with lognormal

distributions and using the thereby obtained parameters for classification. Because of difficulties with the modeling of strokes with different lengths, a classification failed.

Contents

Chapter 1

Introduction

PD is named after James Parkinson, who first described the clinical syndrome in 1817 in "An essay on the shaking palsy". In 1960, three years after dopamine was discovered as a neurotransmitter, Ehringer and Hornykiewicz observed that dopamine concentrations are markedly lower in patients with PD. It is the second most common neurodegenerative disorder in the elderly[Obu20] and affects multiple aspects of the human body. PD affects 1% of the population above 60 years, has an increasing prevalence with age, and is slightly more frequent among men. The onset of the disease is usually at an age of 65 to 70 years and in less than 5% of the cases before the age of 40. The cause of PD is unknown in most cases. However, genetic risk factors can be identified in some cases. Several environmental factors like cigarette smoking, alcohol, vitamin D exposure and urate levels may also influence the risk of disease [Tys17].
Having a system that could autonomously detect PD and its severity, or that is able to assist doctors in their diagnosis, would make the elaborate process of evaluating PD easier. Therefore, methods based on different signals, such as speech, gait and handwriting are being tested [OA20].

1.1 Clinical features

PD belongs to a group of conditions called motor system disorders, which cause unintended or uncontrollable movements of the body. The four cardinal features of PD are: Tremor at rest, Rigidity, Bradykinesia and Postural instability.

1.1.1 Bradykinesia

Bradykinesia is the most characteristic clinical feature of PD and refers to slowness of movement. It results in difficulties with planning, initiating and executing movement. The emotional state of the patient influences Bradykinesia, as well as other PD features. Therefore, an excited patient can for example make quick movements such as catching a ball. Bradykinesia is the features that correlates best with the dopamine deficiency [Jan08].

1.1.2 Tremor

Rest tremor is an easily recognizable symptom of PD. It occurs at a frequency between 4 and 6 Hz, and is almost always observed in the distal part of an extremity but can also involve the lips, chin and jaw. The occurrence of rest tremor differs among patients and during the disease. In one study only 75% of the patient had tremor during of the disease [Jan08].

1.1.3 Rigidity

Rigidity is an early symptom of PD, since it can cause pain. A painful shoulder is one of the most frequent initial manifestations of PD [Jan08].

1.1.4 Postural instability

Postural instability generally manifests in the late stages of PD. For clinical evaluation of postural instability, the pull test, in which the patient is quickly pulled backward or forward by the shoulders, is used. The way how the patient is regaining his balance indicates whether he has an abnormal postural response [Jan08].

1.2 Stages and progression of the disease

In order to describe the different stages of the disease the Hoehn and Yahr (HY) scale [Hoe67] can be used. This scale was originally developed in 1967 and consists of five stages, based on the level of clinical disability:
Stage I: Unilateral involvement only, usually with minimal or no functional impairment.
Stage II: Bilateral or midline involvement, without impairment of balance.
Stage III: Mild to moderate disability with impaired postural reflexes. Patients are physically capable of leading independent lives.

Stage IV: Fully developed, severely disabling disease; the patient is still able to walk and stand unassisted but is markedly incapacitated.
Stage V: Confinement to bed or wheelchair unless aided.
Symptomatic therapy of PD with dopamine replacement strategies including levodopa (L-Dopa) or DA-agonists is associated with improvement of motor symptoms. Nevertheless such treatment has not been shown to significantly alter the progression of the underlying neuronal degeneration in the illness. Studies from the pre-levodopa era have not provided details on the rate of progression of motor impairment. Therefore it is not possible to assess the progression of motor-dysfunction in untreated patients. When extrapolating data from short-term placebo-controlled studies, a progression of motor-dysfunction is found which would lead to a severe disability after less than 10 years. The progression has become markedly slower with effective symptomatic therapies and studies from the post-levodopa ear have found latencies to HY stage 4 or 5 of up to 40 years [Poe06].
Apart from motor function, non-motor functions are also effected by the disease. A study [Hel04] tested 52 subjects who survived 15 years from diagnosis. They observed cognitive decline in 84% and dementia in 48% of the patients. Hallucinations and depression are experienced by 50%.
Hoehn and Yahr found an increased mortality ratio among PD patients of almost the threefold compared to the general population of the same age, race and sex [Hoe67]. Studies in the post-levodopa era found reduced mortality ratios of 1.5 to 2.5 [Poe06].

1.3 Clinical evaluation of the patients

A variety of clinical rating scales for PD exists, some of them are out of date or not fully evaluated for validity and reliability [Jan08]. The Unified Parkinson's Disease Rating Scale (UPDRS) was developed in the 1980 [Goe07], and is the most commonly used rating scale for PD. In 2001 the Movement Disorder Society (MDS), criticized the UPDRS and identified a number of weaknesses and areas needing a review in order to reflect current scientific developments. The effort of the MDS resulted in the development of a new version of the UPDRS. The original core four-part structure was retained, while inconsistencies were addressed and removed. These parts were: Non-motor Aspects of Experiences of Daily Living, Motor Experiences of Daily Living, Motor Examination and Motor Complications [Goe07]. With the revision by the MDS, it was attempted to reach a time estimate of 30 minutes for the final full MDS-UPDRS. To get a more meaningful view on the MDS-UPDRS it can be compared to the HY scale. In 2017 a study [Sko17] about the MDS-UPDRS scores on parts I through IV and their differences based

	HY stage 1	HY stage 2	HY stage 3	HY stage 4	HY stage 5
#Patients	343	1613	754	303	88
$\mu \pm \sigma$	6.5 ± 4.8	11.2 ± 6.6	17.5 ± 7.4	27.3 ± 8.8	37.1 ± 8.3
Range	0–25	0–44	1–45	1–49	10–52

Table 1.1: MDS-UPDRS-III of the different HY stages of the disease

on HY stage and disease duration in a large cohort of patients with PD was conducted. They analyzed a total of 3206 patients with a mean age of 65.8 $\pm$ 10.6 years, 53.3% of which were men. They observed a mean disease duration of 11.5 $\pm$ 4.6 years, and a median HY stage of 2. The mean for the consecutive MDS-UPDRS parts I through IV was 12.19 $\pm$ 7.23, 14.50 $\pm$ 9.64, 34.38 $\pm$ 18.39 and 3.53 $\pm$ 4.35, respectively. Over the HY stages 1 through 5, there was an average increase of the MDS-UPDRS parts I, II, III and IV of 3.8, 7.7, 14.6 and 2.0, respectively. Within 5 years the MDS-UPDRS subscores increased by an average of 1.6, 3.3, 4.2 and 1.4 points consecutively for parts I through IV, respectively. Table 1.1 shows mean, standard deviation and range of MDS-UPDRS part III (MDS-UPDRS-III) for the different HY stages.

1.4 Current situation of PD classification based on handwriting

Since the diagnosis process of PD is time-consuming and costly, there is interest in the research community to automatically monitor the course of PD. Most studies addressing PD detection consider data from on-line handwriting, since this enables capturing the dynamics of the handwriting. The tablet provides exact information about the coordinates and the angle with which the patient put the pen on the tablet. There are tablets that also track the pressure of the pen as well as in-air-movements of the patient. Having the values of all these signals available at an arbitrary time allows making assumptions about the dynamics of the handwriting of the patient. Most of the studies that have considered handwriting assessment to classify PD patients and HC subjects are based on kinematic features, such as the velocity, acceleration and jerk of the strokes [Ros13, Dro14, Dro16, Kot17, Muc18a, MJ19, Zha18, Muc18b, RU19]. Combining these features with the pressure of the pen, as well as the azimuth and altitude angle, has been tested in several studies [Ros13, Dro16, Zha18, RU19]. In recent studies [Imp19], the author classified PD patients and HC subjects by modeling the muscle movement with lognormal distributions. Each stroke a patient performed was then modeled as two of those distributions, one for the agonist

movement and one for the antagonist. In [RU19] the trajectory of the Archimedean spiral was modeled as an amplitude-modulated signal, where the amplitude values are given by a third-order polynomial which is estimated by polynomial regression. They also tested a set of kinematic features with a Support-Vector-Machine (SVM) and achieved an accuracy score of 94.0% on the *spiral* task. Young HC subjects were classified against PD patients. Their PD group was formed with 39 patients (26f) and 40 HCs (16f) and a SVM was used for classification. The used feature set consisted of the output of the statistical functions: mean, standard deviation, maximum value, minimum value, skewness and kurtosis. As input for these functions the original signals from the tablet were used, as well as their first and second derivative. Out of this a 48-dimensional feature-vector was computed. In [Imp19] the author considered a feature set, which also used non-standard statistical functions, like Shannon and Rény entropy, Teager-Kaiser energy, Signal-to-Noise ratio and more. He achieved an accuracy of 88.33% on his dataset, which consisted of 37 PD patients and 28 HCs.

This thesis aims to build on and extend this work. Therefore a classifier based on kinematic features is introduced after a description of the participants, tasks and framework. Afterwards new features based on spectral analysis and a mathematical model for the velocity profile of the pen are proposed and tested.

Chapter 2

Data and Experimental Framework

2.1 Participants

The dataset consists of 49 (22f) healthy controls (HC) and 75 (40f) patients with PD. There is no clinical score for the progression of the disease available for the HC group. For the PD group the MDS-UPDRS-III is available in 53 cases. As shown in Figure 2.1 the MDS-UPDRS-III has the scores 25 and 46 for its first and third quartile respectively, a minimum of 5, a maximum of 65 and 3 outliers with a MDS-UPDRS-III of over 80. Table 2.1 shows the number of available samples by task.

Note that there are fewer samples for the tasks *circletemplate*, *line1* and *line2*. This should be kept in mind for the classification results. Especially for the division of the patients in different groups regarding the severity of the disease, the number of samples correlates with the results of the classification. Figure 2.1 shows the age distribution of the patients. Both classes are age-balanced. The median for the PD group is 62, and for the HC group it is 63. The difference between the first and third quartile is lower for the HC subjects than for the PD patients. Conversely, the difference between the maximum and minimum ages is lower for the PD patient than for the HC subjects. Despite the denser age distribution within the PD subjects, there is not a significant difference that affects the classification.

The data was collected using Wacom Cintiq 13 HD tablets, with visual feedback to the patients using a sampling frequency of 180 Hz. The tablet collected six different signals: the horizontal ($x(t)$) and vertical ($y(t)$) positions as well as the distance of the pen to the surface of the tablet ($z(t)$), the azimuth and altitude angle and the pressure of the pen.

Task	#PD	#PD samples	#HC	#HC samples
alphabet	71	119	49	49
circle	75	124	49	49
circletemplate	55	81	36	36
cube	75	124	49	49
freewriting	73	122	48	48
house	75	124	49	49
id	73	122	49	49
line1	60	94	36	36
line2	60	94	36	36
name	74	123	49	49
numbers	73	122	49	49
rectangles	75	124	49	49
rey	69	118	48	48
rhombus	75	124	49	49
signature	74	120	49	49
spiral	75	124	49	49
spiraltemplate	71	111	48	48

Table 2.1: Sample and subject numbers by task

2.2 Tasks performed by patients

The subjects performed the tasks: *alphabet*, *circle*, *circletemplate*, *cube*, *freewriting*, *house*, *id*, *line1*, *line2*, *name*, *numbers*, *rectangles*, *Rey*, *rhombus*, *signature*, *spiral* and *spiraltemplate*. The suffix "-template" means that the patients drew the sample based on a predefined figure which was displayed on the tablet. The participants wrote the sentence "El abecedario es a,b,...,z" in the task alphabet. In the task ID the number on the identity card was written, a regularly executed task. The task Rey refers to the Rey-Osterrieth complex figure test (ROCF), in which the examinees are asked to reproduce a complicated line drawing. This test is also known for testing patients for dementia. Figure A displays all the tasks (except for the *signature* and *ID*) performed by an HC subject (right) and a PD patient (left).

2.3 Experimental Framework

Most of the current research papers only address the problem classifying PD patients and HC subjects. Therefore, there already exists a variety of solutions as stated in Section 1.4, which

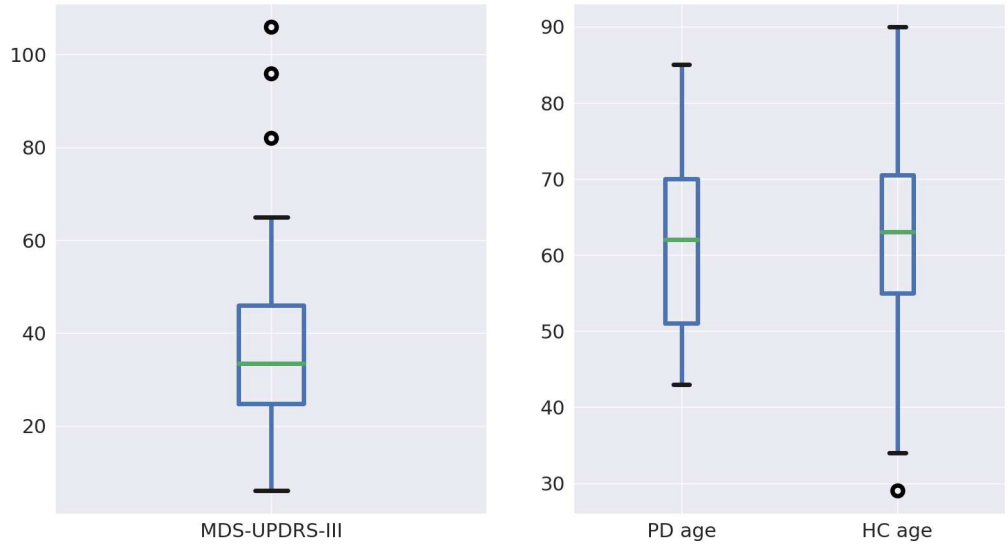


Figure 2.1: Distribution of MDS-UPDRS-III score and distribution of the age of PDs and HCs

achieve high accuracies for this bi-class problem. In this thesis it was attempted to not only find new approaches to this problem, but also to estimate the motor severity of the patients based on the MDS-UPDRS-III scale. However, the problem of predicting this score is a far more advanced problem than diagnosing a person with PD. As explained in Section 1.3 the clinical evaluation of the disease is a complex procedure, as it consists of multiple sub-scales, which then consist of multiple tests. Therefore, when evaluating the MDS-UPDRS-III many aspects of the human body are taken into account, not only the handwriting. Nevertheless, this thesis includes tests for predicting the clinical score solely through handwriting.

Chapter 3

Kinematic analysis

Current classification methods [RU19, Imp19] are often based on kinematic features. In this thesis basic kinematic features are used to see how they perform on the dataset.

3.1 Kinematic features

The features used for classification are based on the original signals: x, y, z, pressure, azimuth and altitude angle, as well as two computed values: the trajectory $r(t)$ and Θ, with $r(t) = \sqrt{x(t)^2 + y(t)^2}$ and $\Theta = arctan(\frac{y}{x})$. For each of these signals and their first and second derivatives the standard deviation, the skewness and the kurtosis are taken. Additionally, the average of the signals, but not of their derivatives were computed. Together these features formed a 80-dimensional feature vector per drawing.

3.2 Experiments

In order to classify the data a Support-Vector-Machine (SVM) is used. Gaussian and polynomial kernels with different degrees were tested with the SVM. Early experiments have shown that the Gaussian kernel performed better than polynomial kernels. Therefore, all the later evaluation was done using a Gaussian kernel. Before a test is run, the hyperparameters are optimized. For such a purpose, a randomized search with a 5-fold cross-validation is used. The algorithm searches for the best hyperparameters based on probability density functions (pdf). In order to see which pdf gets the best results, the log-uniform distribution

$$f(x; a, b) = \frac{1}{x \log(\frac{b}{a})}$$

and the exponential distribution

$$f(x;\lambda) = \lambda \exp(-\lambda x)$$

are both tested with different hyperparameters. Since the dataset is small, the results heavily depend on which data is used as validation-set. Thus, in order to get more robust scores, the classification process is run 10 times. Before each run the data is shuffled and a new validation-set is chosen. Then a completely new classifier is trained, and the average score off all classifiers is taken to see which pdf performs best. Because of the small data-set this process does not take too much time and is performed for each task. This procedure was done for all tests in this thesis including the other chapters with spectral features and fitting of lognormal distributions. Since some PD patients had multiple sessions where their MDS-UPDRS-III was taken, there were several drawing samples of them. When dividing the dataset into train- and test-sets, it was taken care of that all samples of a patient always were in only one of the sets, thus the reported results are always subject-independent.

3.3 Results of the kinematic analysis

The results were produced using the hyperparameters calculated beforehand. There are two types of tests performed with the tasks. First each task was taken alone to make a classifier. Then it was tested how combinations of different tasks perform. Combinations up to three different tasks were tested. Because of the exponential increase of possibilities, combinations of more than 3 different tasks took to long to compute.

3.3.1 Parkinson's disease classification

Individual task

First each classifier was build based on one task alone. Table 3.1 shows the results obtained for the classification for each task performed by the patients.

The last column refers to the **A**rea **U**nder the receiver operating characteristic **C**urve, or ROC curve. Before comparing the results it needs to be said, that there were fewer samples available for the tasks *circletemplate*, *line1* and *line2*. Among the best performing tasks were *circle*, *rectangles*, *rhombus* and *spiral*. All those tasks have in common, that they are simple figures, which are drawn similarly by different subjects. For example a circle can theoretically only vary in its radius, whereas most people draw numbers and letters differently. This is also represented in the

	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet	65.0	82.7	62.8	0.709	0.753
circle	76.9	88.1	78.5	0.827	0.812
circletemplate	53.4	50.2	54.9	0.477	0.755
cube	64.7	78.9	69.0	0.714	0.720
freewriting	65.0	79.8	66.5	0.717	0.722
house	67.4	84.8	67.3	0.742	0.734
id	61.9	79.8	62.1	0.691	0.683
line1	49.6	53.9	47.3	0.445	0.763
line2	46.6	68.5	35.3	0.396	0.768
name	63.4	83.7	59.7	0.682	0.702
numbers	54.1	84.0	41.2	0.535	0.693
rectangles	74.3	86.7	75.6	0.801	0.827
rey	67.7	82.9	68.5	0.746	0.736
rhombus	73.3	89.5	71.1	0.787	0.813
signature	55.3	48.0	58.5	0.513	0.767
spiral	70.2	88.4	67.3	0.758	0.782
spiraltemplate	64.4	80.1	67.6	0.726	0.707

Table 3.1: Results of classifier with kinematic features

bad results of the *numbers*, *signature* and *name* tasks. However there are some outliers like *cube*, *house* and *rey*. The outcome of these tasks should also not vary too much when being drawn from different persons, but they only have an accuracy comparable to the *alphabet* task. These tasks are more complex than the previous mentioned *circle*, *rectangles* etc., and therefore they are more likely to have a bigger variance within their velocity profile. For example while the *rectangles* consist of horizontal and vertical lines which have about the same size, the *cube* also has shorter diagonal lines.

Multiple tasks

The different tasks were combined by concatenating the features of the tasks for each patient. If there were multiple samples of a patient present, a sample from one task was only combined with one sample from the other task. Due to the big amount of possible combinations the optimization of the hyperparameters was shortened in order to save computation time. While previously several distributions for the randomized optimization were tested, now the already existing results for the distribution were taken from the one task classifier. The statistics were then calculated in the same way as before as a mean value of several independent classifiers with a 5-fold cross

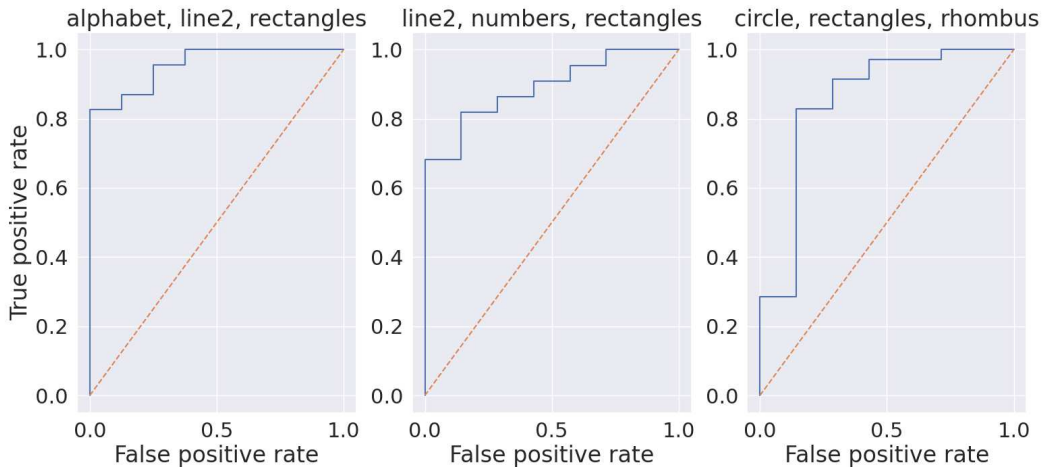


Figure 3.1: ROC-curves of the two best performing combinations together with the combination of the individually best tasks.

validation and a randomized hyperparameter optimization. In order to combine different tasks it was also tested to not combine the feature-vectors but the classifiers which were only build on one task. So the final classifier made its decision based on the weighted sum of the previous one-task classifiers. The weight of a classifier was determined by its performance on the task it was trained on. This classifier did not return good results.

The classifier based on the combination of the features has the results shown in table B.1.

There are several combinations which led to a significant improvement of the classifiers. It seems that those consisting of tasks which have a big difference regarding their complexity, e.g. combinations including *rectangles* and *numbers*, achieve among the highest scores. The *numbers* task itself however has one of the lowest scores. The second highest AUC score of 0.901 is achieved by the combination *line2*, *numbers* and *rectangles*, while the highest AUC (0.926) is the same combination with *alphabet* instead of *numbers*. Conversely, tasks that have a similar structure and perform badly as standalone tasks like *cube* and *house*, also have bad results when combined. Combinations like *circle*, *rectangles*, *spiral*, where all tasks achieve good results when used in a standalone classifier, also do well when combined. However, a greater improvement is shown when one complex task, like *alphabet* or *numbers* is added. The combination of features from the three best one-task classifiers, *circle*, *rectangles* and *rhombus*, achieves an AUC value of 0.852 which is only slightly higher than the *rectangles* task itself with 0.827. Figure 3.1 shows the ROC-curves of the two best performing models together with the combination of the individually best tasks.

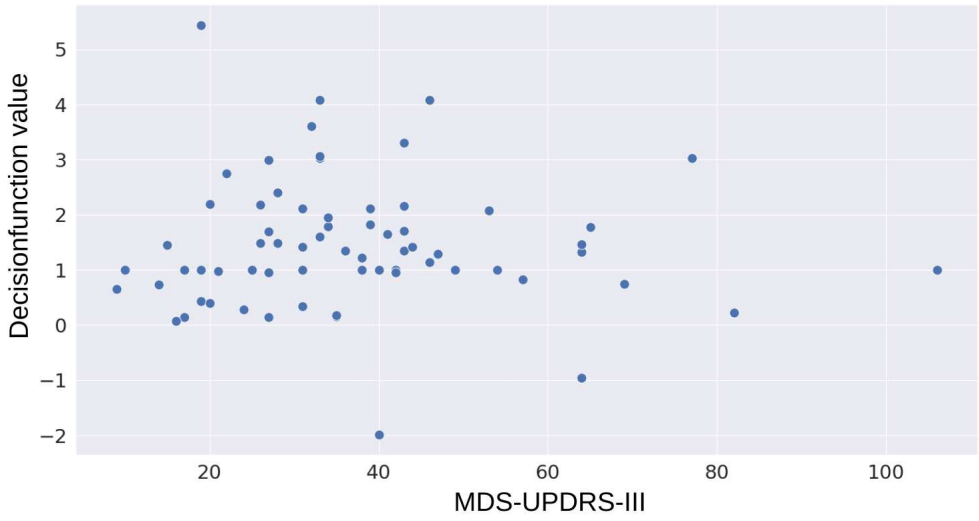


Figure 3.2: MDS-UPDRS-III with value of the decision function based on *spiral* task

3.3.2 Evaluation of the disease severity of the patients

In order to predict the MDS-UPDRS-III of a patient two different methods were tested. First it was searched for correlations between the output of the decision function of the SVM and the clinical score. Figure 3.2 shows the results on the basis of the *spiral* task. It seems that a higher MDS-UPDRS-III does not necessarily result in a clearer decision. Therefore, no more tests were performed with the decision function. Second it was attempted to fit the score via Support Vector Regression (SVR). The following results were produced with the *spiral* task. HC subjects with no available score got a score of 0. PD patients with no available score were left out. Table 3.2 shows the results of the regression problem for the *spiral* task.

P, ρ and MAE in Table 3.2 refers to the Pearson correlation coefficient, the Spearman correlation coefficient and the Mean Absolute Error. The low values for P and ρ show that there is close to no correlation between the results of the SVR and the actual clinical score for most of the tasks. The MAE shows values of around 18 for every task. The tasks *rhombus*, *line1*, *line2* and *circletemplate* achieve a Spearman correlation coefficient of over 0.30, showing that there is some correlation for these tasks. However their MAE does not differ from the ones of the other tasks. When looking at the predicted scores of the SVR, it always shows scores of around 20. Therefore the regression failed.

Task	P	ρ	MAE
alphabet	0.05	0.08	18.0
circle	0.20	0.23	18.3
circletemplate	0.26	0.36	19.3
cube	0.02	0.02	18.6
freewriting	0.23	0.26	18.6
house	0.23	0.19	19.5
id	0.27	0.29	17.5
line1	0.25	0.33	19.3
line2	0.16	0.31	19.6
name	0.26	0.25	18.0
numbers	0.27	0.16	17.9
rectangles	0.21	0.21	19.5
rey	-0.02	0.01	18.9
rhombus	0.27	0.30	18.9
signature	0.26	0.28	18.3
spiral	0.23	0.29	19.0
spiraltemplate	0.24	0.29	18.2

Table 3.2: Results of SVR with kinematic features

3.3.3 Discrimination of patients in different levels of the disease

Since a prediction of the MDS-UPDRS-III failed, the MDS-UPDRS-III was divided into ranges. The thresholds for the different classes were 15, 25, and 40, resulting in 4 classes, which will be referred to as class 1, class 2, class 3 and class 4 respectively. These thresholds were chosen, so that every class has enough samples to get reliable results and so that there are two classes for subjects with a low score.

To get more meaningful results, the test is run 50 times while shuffling the data between each test run. The average of the results is then shown in the table. Because the amount of data is limited, it is made sure that the classifier has seen each class at least 6 times. In the test set at least one instance of each class must be present.

In table 3.3 the results of the classification are shown. The results show an improvement over the previous test. Predicting the MDS-UPDRS-III itself always returned a score of around 20, meaning the regression failed completely. Here we see that some tasks do not fail completely, since they perform better than random. Also, the tasks which performed best in the classification of PD like *circle*, *rectangles*, *spiral*, perform best in the classification of the different levels. Complex tasks like *freewriting*, *numbers* and *signature* have again a poor performance.

	Accuracy	Precision				Recall				F1			
	All Classes	[-15] UPDRS	[15-25] UPDRS	[25-40] UPDRS	[40-] UPDRS	[-15] UPDRS	[15-25] UPDRS	[25-40] UPDRS	[40-] UPDRS	[-15] UPDRS	[15-25] UPDRS	[25-40] UPDRS	[40-] UPDRS
alphabet	23.12 %	55.21 %	8.63 %	20.32 %	33.24 %	70.18 %	11.48 %	27.74 %	47.90 %	60.49 %	9.19 %	22.08 %	37.22 %
circle	30.98 %	69.42 %	25.22 %	25.45 %	28.33 %	78.32 %	53.63 %	42.17 %	35.55 %	72.07 %	30.97 %	30.96 %	29.38 %
circletemplate	11.74 %	26.56 %	27.10 %	10.73 %	9.96 %	62.85 %	44.80 %	39.20 %	30.40 %	36.28 %	25.82 %	15.54 %	13.41 %
cube	16.58 %	53.04 %	7.97 %	20.77 %	24.46 %	45.40 %	24.83 %	41.56 %	35.17 %	46.57 %	10.12 %	25.31 %	23.12 %
freewriting	12.95 %	51.59 %	5.86 %	28.40 %	17.99 %	56.84 %	34.50 %	36.61 %	44.75 %	52.75 %	9.84 %	29.81 %	23.57 %
house	20.30 %	53.79 %	11.65 %	19.67 %	36.03 %	64.12 %	25.49 %	29.81 %	53.29 %	57.42 %	14.78 %	22.85 %	40.82 %
id	23.81 %	57.35 %	16.97 %	29.02 %	30.73 %	62.63 %	35.64 %	43.34 %	50.55 %	58.62 %	21.43 %	33.13 %	35.97 %
line1	7.66 %	28.58 %	5.88 %	20.82 %	14.45 %	67.71 %	38.40 %	53.77 %	55.33 %	39.40 %	9.36 %	24.15 %	22.24 %
line2	11.93 %	32.09 %	31.03 %	10.65 %	8.87 %	71.51 %	41.18 %	39.70 %	40.13 %	42.28 %	29.82 %	15.55 %	14.09 %
name	25.86 %	60.59 %	7.54 %	18.65 %	28.68 %	76.08 %	10.65 %	33.91 %	46.31 %	66.26 %	6.93 %	21.98 %	34.02 %
numbers	12.19 %	38.60 %	5.96 %	14.36 %	50.46 %	67.04 %	34.37 %	49.66 %	50.99 %	47.63 %	9.94 %	21.46 %	47.84 %
rectangles	27.83 %	67.59 %	26.32 %	23.83 %	39.62 %	70.72 %	37.03 %	42.02 %	55.34 %	67.49 %	27.32 %	28.40 %	44.14 %
rey	23.38 %	58.19 %	15.35 %	29.80 %	30.35 %	64.32 %	44.78 %	31.70 %	46.65 %	59.93 %	21.67 %	27.63 %	35.13 %
rhombus	29.42 %	66.15 %	40.69 %	27.37 %	25.39 %	77.54 %	33.97 %	42.51 %	44.21 %	69.92 %	33.28 %	31.50 %	29.76 %
signature	7.16 %	22.75 %	5.99 %	14.41 %	11.52 %	52.55 %	44.38 %	60.06 %	49.10 %	30.94 %	10.20 %	22.31 %	17.71 %
spiral	35.89 %	65.78 %	23.48 %	33.97 %	32.31 %	78.49 %	22.72 %	40.23 %	53.54 %	70.62 %	21.89 %	33.80 %	37.91 %
spiraltemplate	26.26 %	56.57 %	6.85 %	22.35 %	23.84 %	60.00 %	4.57 %	21.47 %	37.23 %	56.36 %	4.89 %	20.57 %	27.17 %

Table 3.3: Results predicting the disease severity of PD patients in four classes

The classification of class 1 achieves the best results. This could be due to the fact that all HCs are given a score of 0 and therefore belong to the first class, resulting in an unbalanced dataset. Because of this imbalance, the classes are weighted. Therefore, this difference in the results could mean that the scores of the other classes improve as well with a larger dataset. But it could also mean, that the classifier just detects healthy people. Since the F1 score is a combination of recall and precision, the following analysis will be done using this score, unless explicitly stated otherwise. When looking at more complex tasks, the overall accuracy is worse than the accuracy of simple shapes, like it was already with the bi-class problem. Furthermore, those complex tasks also have an imbalance between the PD classes 2, 3 and 4. Numbers as an example has a score of under 10% for class 2 and a score of nearly 48% for the fourth class. This imbalance can also be observed in tasks like *alphabet*, *freewriting*, *house* and others. Simpler shapes like *spiral* and *rectangles* also have an imbalance but not to the same extent as the previous mentioned tasks. *Circle* and *rhombus* have both nearly balanced scores for the classes 2, 3 and 4. They also have the highest scores for the overall accuracy, except for *spiral*. Even though the classification works to some extent, the highest accuracy is only 35% and thus the classifier is far away from providing good results.

Chapter 4

Spectral analysis

As stated in the introduction, the rest tremor of a PD patient ranges between 4 and 6 Hz. The goal is to try to detect changes in the movement which occur in different spectral bands.

4.1 Spectrograms of trajectory

To capture movement in all directions, the trajectory $r(x, y) = \sqrt{x^2 + y^2}$ is used for calculating the feature-vectors in the later classification. However, different signals were tested as an input for this classifier. Besides the trajectory, the movement in the horizontal and vertical directions, the azimuth and altitude angles, as well as Θ and the derivative of the trajectory were tested. In addition, these signal were combined to caculate the feature vector. Using the trajectory alone led to the best results. Figure 4.1 shows the spectrograms and the power spectral densities (PSD) of the trajectories of the Archimedean spirals, computed for three patients in low, intermediate and severe stages of the disease. The left column displays the drawing itself with the color indicating the pressure of the pen. The middle column shows the spectrogram between 0 to 20 Hz and the right column shows the PSD. In the first row the patient had a low MDS-UPDRS-III (19). As the drawing shows, there is no visible tremor. The patient in the second row has a MDS-UPDRS-III score of 27 and a highly visible tremor. Additionally, the drawing shows that he removed the pen from the surface of the tablet several times. The last patient is in a severe state of the disease with an MDS-UPDRS-III score of 65. Again there is a highly visible tremor and the patient was not able to draw the spiral in one continuous line. The spectrogram was computed with a fast-fourier-transform (FFT), with the data split into segments with a length of 0.7 seconds (256 samples). The overlap of the segments is a tenth of the segment-length. Before applying the FFT on a segment, linear trends were removed. Meaning a linear fit was made

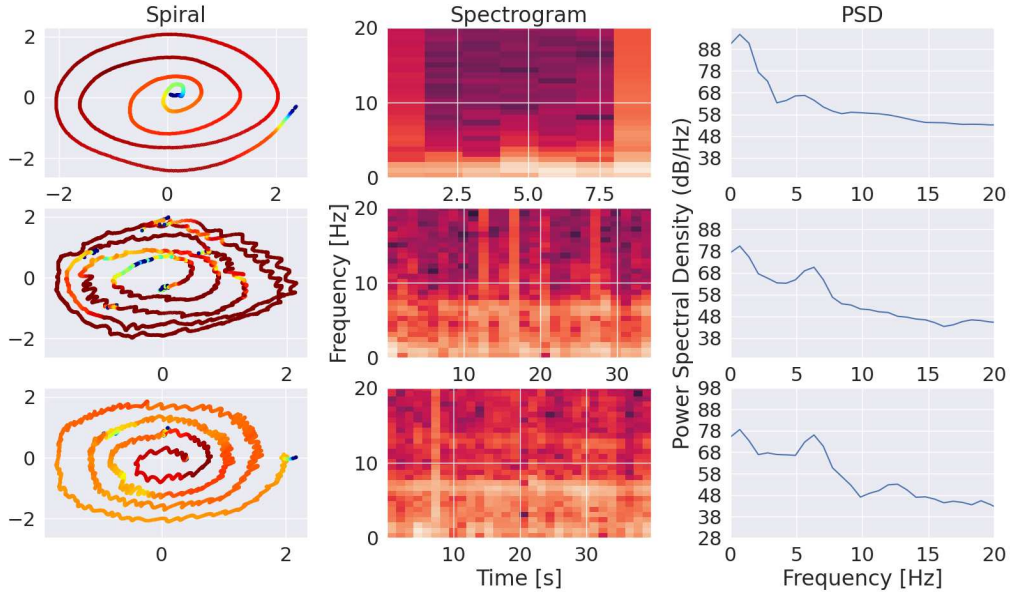


Figure 4.1: Spectrograms and PSD of PD patients

and then subtracted from the data. The color of the spectrogram is the power-spectral-density in (dB/Hz), with dark colors indicating low values and bright colors indicating high values. The power-spectral-density (PSD), as it can be seen in the right column, is the average over time of the spectrogram. All PSD-plots have two peaks. The first one is the highest in all three cases and occurs at a frequency of around 1 Hz. Notice how all the PSD plots have the second peak between 5 and 7.5 Hz, and the first sample with the lowest visible tremor also has the lowest value for the second peak. Furthermore, the first peak in the first sample is higher compared to the other first peaks in the samples with higher visible tremor. Apart from those two peaks the value of the PSD is continuously decreasing with frequency. There is an additional third peak around 12.5 Hz that can be seen in the third sample, which did not occur in other samples. The last two samples also have horizontal lines at various times in the spectrogram. Finally, note also that the patients in the second and third sample took longer to complete the task. Figure 4.2 displays three samples of HC subjects. Even though it seems that there is a second peak in the area of 5 to 7.5 Hz, it is less distinctive than those observed with the PD patients. The power of the first two peaks is higher in the samples of the HC subjects. Apart from the first peaks the PSD values are again decreasing. The peaks from the PSD-plot are also visible in spectrograms as bright horizontal lines at the corresponding frequencies. There is a big difference in the duration of the

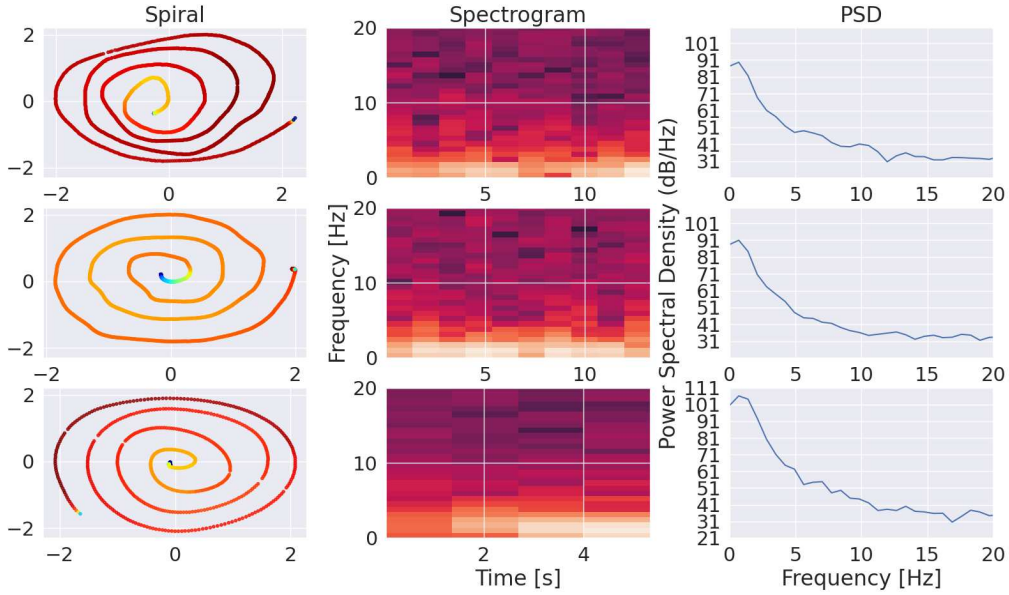


Figure 4.2: Spectrograms and PSD of HC subjects

handwriting of the subjects. The last one took less than half of the time of the previous ones. The first two HC subject in the plots took longer to complete the drawing than the first PD patient. In the second and third sample of the PD patients are vertical bright lines in the spectrograms. They could be related to a change of velocity in the drawing. For example in the pen-up or pen-down transitions, when patients start or stop a new stroke.

4.2 Spectral features

With the information gathered from the plot the following features were extracted: the frequencies and energies where the first two spectral peaks appear, the frequency of the minimum before the second peak and the Shannon entropy of the PSD over all frequencies, as well as the entropies over the frequency-ranges $[0, 4]$Hz and $[4, 10]$Hz.

Before getting to the results of the classification, there are some other features based on the characteristics of the spectrograms that were tested, some of which would not have been applicable on other tasks. The example from the previous section has shown that the duration to complete the drawing cannot be used alone for classification. First of all, there are some people among HC subjects and PD patients likewise, who drew their spiral fast and some, who did not. There are

drawings in the PD class, which took less than 5 seconds. However, it seems to be that the tasks which were performed faster have a higher first peak. Additionally, it depends on how many turns the spiral has. The amount of turns in a spiral ranged from 3 to 10. It was tried to add the time along with the turns of the spiral to the features, however, the results wre not satisfactory. In order to find some pattern for the occurrence of the vertical lines in the spectrogram the spectral centroids [Pee03] were calculated:

$$\frac{\sum_{x=0}^{max(frequency)} x|F(x)|^2}{\sum_{x=0}^{max(frequency)}|F(x)|^2}$$

F refers to the Fourier transform. A normalized version of this sum was tested as well. No pattern was found in the spectral centroid, thus the horizontal lines in the spectrogram seemed to occur non-regularly.

4.3 Results of spectral analysis

4.3.1 Parkinson's disease classification

Again the first tests are about classifying the disease itself. The optimization of the hyperparameters and the calculation of the results, regarding cross validation, shuffling train and test data and class imbalance, was performed as described an Section 3.3.

Individual task

Table 4.1 shows the results of the classification with one task. First of all the results look overall better than with the kinematic features, which had AUC values of slightly over 80% for the best tasks. Here the best tasks achieve scores of over 95%. The distribution of the scores differs from the one with the kinematic features, since previously the tasks with simple shapes, such as *circle*, *rectangles*, *rhombus* and *spiral* performed best. Now *circle* and *rectangles* have, except for the line tasks which have fewer samples available and the *freewriting* task, the worst results. It seems that these tasks are not complex enough to provide good results. The *spiral* remained among the best tasks. *Circle* and *house* have both increased scores. It seems that since both consist of a combination of diagonal, vertical and horizontal lines, these kinds of drawings are well suited for classification. However, there is also the Rey figure which also contains a lot of those lines and only has an AUC score of 88%. This figure is far more complex than *house* or *cube* and its lines are of different lengths. It is possible that this causes the classifier to fail more often, since

	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet	76.5	81.5	86.0	0.830	0.784
circle	83.0	87.2	89.2	0.879	0.776
circletemplate	86.7	90.7	90.8	0.904	0.839
cube	94.5	96.0	96.2	0.960	0.947
freewriting	68.0	79.0	76.3	0.772	0.630
house	95.8	98.6	95.3	0.968	0.972
id	77.8	82.9	87.8	0.849	0.797
line1	74.4	82.9	81.7	0.819	0.727
line2	77.1	84.9	83.2	0.836	0.726
name	76.2	82.6	85.1	0.833	0.794
numbers	87.2	88.9	94.1	0.911	0.892
rectangles	81.9	87.4	88.1	0.875	0.769
rey	80.7	84.2	89.9	0.864	0.875
rhombus	86.9	87.9	94.7	0.909	0.920
signature	95.8	98.4	95.6	0.969	0.955
spiral	94.1	95.3	96.4	0.957	0.941
spiraltemplate	94.3	95.6	96.2	0.958	0.927

Table 4.1: Results of classifier with spectral features

tasks with a lot of short strokes such as *alphabet*, *freewriting*, *id* and *numbers* don't have good results. Signature falls out of the scheme since *alphabet* and *freewriting* don't perform well, but *signature* has the second best score. It also contains strokes of different lengths. The *signature* is a task that everyone performs regularly throughout his life, therefore it could be that the writing-style differs from the *alphabet* or from *freewriting*. But since this is also the case for the *id*, and *id* has an AUC under 0.8, *signature* continues to be an outlier.

Multiple tasks

Table C.1 shows the results for different combinations of tasks. They were combined by concatenating the feature vectors. In contrast to the combination of the kinematic features, using multiple tasks for classification does not lead to better scores. With the kinematic features the observation was made, that with tasks which differ in their complexity a combination produced higher accuracies. This pattern cannot be observed here. The best combination is *cube*, *house*. The tasks which performed best as standalone classifiers. However, the *cube*, *house* combination has a lower score than *cube* or *house* alone. Furthermore, *cube*, *house* was the only combination to achieve an AUC over 90%.

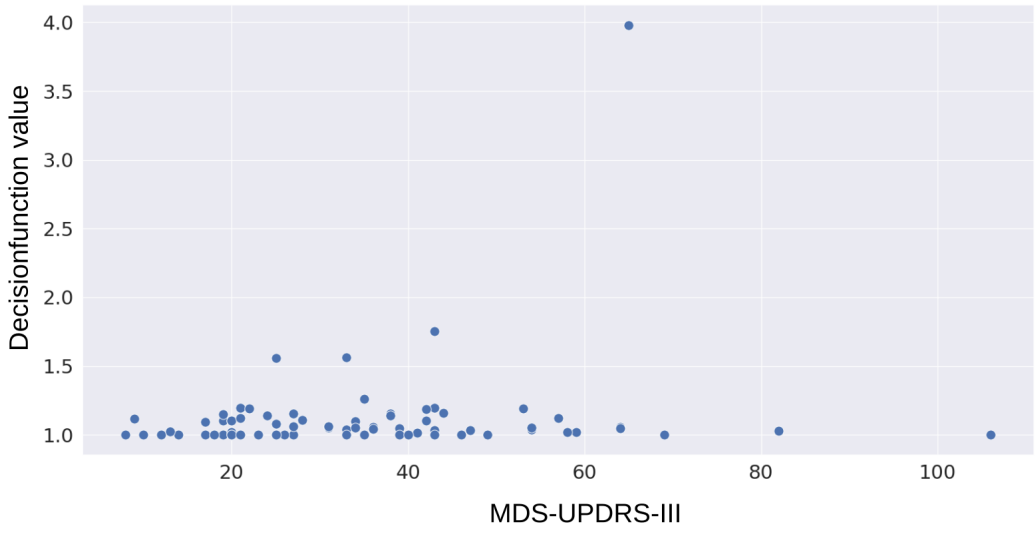


Figure 4.3: MDS-UPDRS-III with value of the decision function based on *spiral* task

4.3.2 Evaluation of the disease severity of the patients

It was again attempted to find correlations between the decision boundary in the SVM and the MDS-UPDRS-III. In Figure 4.3 the clinical score is plotted against the value of the decision boundary. Compared to the plot of the decision boundary of the kinematic features in Figure 3.2, it seems that this time the decision boundary looks less random when plotted against the MDS-UPDRS-III. However most of the samples have a score close to one. The samples from the outlier with the highest decision function value, the one with the second highest value and the sample from the patient with a clinical score of 82 are shown in Figure 4.4 in that order. The tremor in the first sample is highly visible, whereas the patient with the highest clinical score only has a low tremor, while the second sample lies in between. Hence it could be possible that the score of the classifier correlates with the tremor, which does not necessarily correlate with the clinical score. Table 4.2 displays the results of the SVR. The regression always results in values around 20-25, not depending on the actual clinical score of the patient. This is shown by the low values of the correlation coefficients. Compared to the results with the kinematic features in Table 3.2, the MAE looks similar, while the correlation coefficients are even closer to zero. So despite the spectral features resulting in an improvement over the kinematic ones for the bi-class problem, no improvement can be found for the prediction of the clinical score.

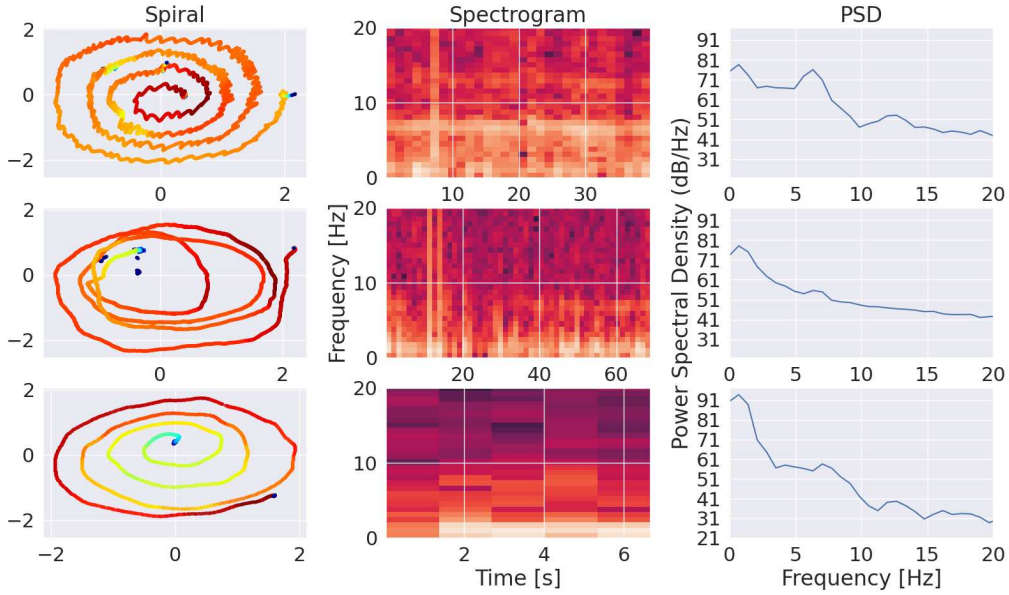


Figure 4.4: Samples from the highest (1. row) and second highest (2. row) outlier from Figure 4.3. The third sample is from a patient with a high clinical score but with a low decision function value.

4.3.3 Discrimination of patients in different levels of the disease

Because of the failure of the SVR, the classification with different levels of the disease is tested again. The classes are the same as in the previous chapter and the statistics were also produced in the same way. The results are shown in Table 4.3. The first thing to notice is that the results don't look much better than with the kinematic features. As a reminder, the kinematic features had accuracies in the range from 7% to 35%. Here the results are slighly lower but within the same range. This stand in contrast to the previously achieved improvement with the classification of the disease itself. Note that there is the same pattern of well performing tasks in disease classification and severity classification. House performed best in both problems.

Task	P	ρ	MAE
alphabet	-0.02	-0.03	18.4
circle	-0.07	-0.13	20.0
circletemplate	0.00	-0.07	19.6
cube	0.06	0.07	19.6
freewriting	-0.11	-0.11	18.0
house	0.17	0.15	19.1
id	0.02	0.05	18.6
line1	0.07	0.04	20.4
line2	0.21	0.14	19.1
name	-0.04	-0.05	19.2
numbers	0.08	0.04	17.9
rectangles	-0.00	-0.02	19.2
rey	-0.09	-0.08	18.4
rhombus	0.15	0.14	19.6
signature	0.16	0.13	17.9
spiral	0.18	0.17	19.4
spiraltemplate	0.16	0.08	19.1

Table 4.2: Results for SVR with spectral features

	Accuracy	Precision				Recall				F1			
	All Classes	[-15] UPDRS	[15-25] UPDRS	[25-40] UPDRS	[40-] UPDRS	[-15] UPDRS	[15-25] UPDRS	[25-40] UPDRS	[40-] UPDRS	[-15] UPDRS	[15-25] UPDRS	[25-40] UPDRS	[40-] UPDRS
alphabet	16.04 %	60.22 %	5.35 %	26.24 %	28.06 %	46.69 %	16.91 %	34.59 %	41.48 %	50.44 %	7.12 %	26.70 %	32.27 %
circle	17.75 %	54.90 %	13.39 %	29.97 %	19.32 %	53.14 %	27.42 %	38.41 %	17.74 %	52.52 %	17.33 %	30.53 %	16.04 %
circletemplate	27.08 %	74.84 %	23.96 %	29.24 %	36.38 %	76.89 %	32.40 %	38.24 %	45.00 %	73.93 %	23.97 %	29.32 %	35.38 %
cube	24.32 %	88.98 %	13.53 %	25.90 %	30.12 %	82.41 %	29.75 %	40.18 %	44.44 %	84.97 %	16.24 %	29.86 %	33.95 %
freewriting	15.75 %	41.50 %	21.31 %	32.19 %	22.64 %	40.01 %	39.11 %	36.07 %	42.69 %	38.78 %	25.93 %	32.47 %	28.14 %
house	29.65 %	92.22 %	18.79 %	20.43 %	38.51 %	83.49 %	50.08 %	36.73 %	61.49 %	87.12 %	25.97 %	25.24 %	45.08 %
id	24.90 %	58.71 %	2.94 %	36.15 %	30.69 %	59.85 %	4.50 %	40.59 %	33.52 %	58.07 %	3.34 %	34.56 %	28.85 %
line1	19.62 %	61.26 %	21.33 %	18.89 %	33.44 %	66.38 %	35.60 %	26.60 %	45.72 %	61.76 %	23.94 %	19.34 %	36.76 %
line2	19.87 %	58.77 %	19.41 %	18.26 %	32.26 %	57.92 %	19.57 %	22.04 %	59.50 %	56.04 %	17.27 %	17.93 %	40.12 %
name	13.87 %	60.18 %	14.14 %	16.75 %	31.56 %	63.48 %	45.69 %	32.15 %	36.39 %	60.54 %	19.91 %	19.91 %	31.61 %
numbers	25.12 %	73.44 %	27.35 %	20.49 %	25.55 %	68.17 %	40.05 %	33.37 %	28.95 %	69.32 %	29.69 %	23.39 %	25.32 %
rectangles	21.43 %	60.32 %	19.27 %	13.79 %	26.03 %	57.48 %	31.00 %	17.70 %	34.77 %	57.14 %	22.07 %	13.97 %	28.18 %
rey	19.38 %	72.65 %	17.99 %	25.71 %	29.33 %	67.62 %	41.82 %	48.64 %	40.15 %	67.87 %	23.33 %	31.60 %	32.34 %
rhombus	18.58 %	76.55 %	16.71 %	22.63 %	29.95 %	69.87 %	35.53 %	34.61 %	46.85 %	71.69 %	18.72 %	25.39 %	32.50 %
signature	24.73 %	84.64 %	13.82 %	27.69 %	22.35 %	84.41 %	22.12 %	47.44 %	40.77 %	83.84 %	15.23 %	33.05 %	27.33 %
spiral	25.57 %	80.09 %	12.92 %	32.04 %	29.83 %	79.73 %	27.54 %	38.18 %	42.56 %	79.20 %	16.22 %	33.30 %	33.45 %
spiraltemplate	26.70 %	86.22 %	18.39 %	24.59 %	33.79 %	80.22 %	40.36 %	35.75 %	60.68 %	82.14 %	23.85 %	27.19 %	41.21 %

Table 4.3: Results predicting the disease severity of PD patients in four classes based on spectral features

When looking at the F1-score, there is again a pattern of increasing scores from the classes 2 to 4. Apart from that, the best results for these classes are around 30 %, similar to the ones with the kinematic features.
The prediction of class 1 seems to be more successful with the spectral features. Here *house* performs best with a score of 87%. This matches the improved results in the PD classification problem, since the HC subjects belong to this class. After all, this classifier is not advanced enough to offer a proper solution for this problem.

4.4 Combining kinematic and spectral analysis

As previous results have shown (cf. Table 3.1, Table 4.1), both kinematic and spectral features can be used for classification. While some tasks have converse results when used with kinematic and spectral features, like the *cube*, which has low scores for the kinematic and high scores for the spectral features, other tasks perform well with both feature sets, like the *spiral*. In this section the features were combined to test whether they complement each other or not. The results were produced in the same way as when combining multiple tasks. Table 4.4 shows the results of the classification. Compared to the standalone spectral features the AUC values are now lower for every task. Adding the kinematic features did not lead to an improvement over the spectral features. This behavior seems to be similar to the combination of the spectral features of different tasks: Since the spectral features of one task alone achieve extraordinary high scores, adding more features only leads to a decrease in said scores.

	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet	68.0	69.3	96.8	0.803	0.532
circle	72.3	72.5	99.0	0.835	0.551
circletemplate	66.6	67.3	88.6	0.754	0.565
cube	68.8	75.8	84.5	0.787	0.643
freewriting	69.3	73.3	91.2	0.806	0.605
house	71.2	81.8	78.7	0.790	0.721
id	68.0	67.8	96.9	0.795	0.517
line1	70.0	72.6	91.0	0.798	0.579
line2	73.8	75.3	96.9	0.841	0.597
name	71.2	73.4	94.4	0.819	0.598
numbers	66.9	66.2	87.6	0.746	0.542
rectangles	72.5	73.6	97.5	0.834	0.590
rey	66.4	68.2	89.4	0.765	0.509
rhombus	71.1	71.9	98.0	0.824	0.555
signature	70.5	76.2	86.8	0.803	0.661
spiral	70.8	77.2	86.6	0.804	0.653
spiraltemplate	66.2	78.0	72.3	0.740	0.688

Table 4.4: Results of PD classification with combined kinematic and spectral features

Chapter 5

Analysis of fitting lognormal distributions

In this chapter the classification is done by modeling the strokes of the patient. To understand the basic pattern of a velocity profile, many studies have been conducted. A bell-shaped profile was evaluated in several studies [Lac83, Mor81, Soe81, Lon97]. Plamondon proposes a kinematic theory, which described a synergy in terms of the agonist and antagonist neuromuscular systems [Pla95]. It shows that these systems have a lognormal impulse response that results from the limiting behavior of a large number of interdependent neuromuscular networks. The resulting delta lognormal model can describe and reproduce the velocity patterns.

5.1 Modeling agonist and antagonist movement with lognormal distributions

The estimation of the seven parameters such that the velocity profile can be fitted, remains an open problem. The delta-lognormal model is the kernel of the Kinematic Theory of Rapid Human Movements, proposed by Plamondon [Pla95]. This theory describes the velocity by the following equation:

$$v(t) = D_1 \Lambda(t; t_0, \mu_1, \sigma_1^2) - D_2 \Lambda(t; t_0, \mu_2, \sigma_2^2)$$

where,

$$\Lambda(t; t_0, \mu, \sigma^2) = \begin{cases} \frac{1}{\sigma\sqrt{2\pi}(t-t_0)} \exp\left\{-\frac{1}{2\sigma^2}(\ln(t-t_0)-\mu)^2)\right\} & \text{if } t > t_0 \\ 0 & \text{elsewhere} \end{cases}$$

and,

D_1, D_2: the amplitude of the distributions. They indicate the distance covered by the movement.

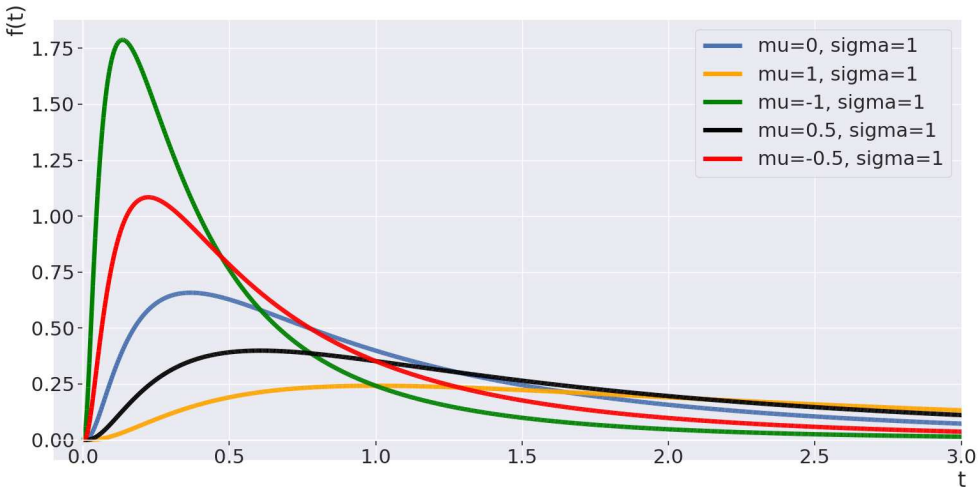


Figure 5.1: Lognormal distributions with different values for μ

t_0: the time shift parameters. It represent the time occurrence of the stroke.
μ_1, μ_2: the logtime delay. They express the time delays of the neuromuscular systems on a logarithmic scale. Figure 5.1 shows the lognormal distribution with different values for the parameter μ.
σ_1, σ_2: the logresponse times, the response times of the neuromuscular systems on a logarithmic scale. Figure 5.2 shows plots with different σ-values.

5.2 The XZERO-algorithm

The XZERO-algorithm is based on exploiting the analytical relationship of three time-indexes of a lognormal profile $\Lambda(t)$. These indexes correspond to the maximum t_m, where $d\Lambda(t)/dt = 0$, and the inflexion points t_{inf1}, t_{inf2}, where $d^2\Lambda(t)/dt^2 = 0$ The name of the algorithm itself, XZERO, refers to these zero crossings.

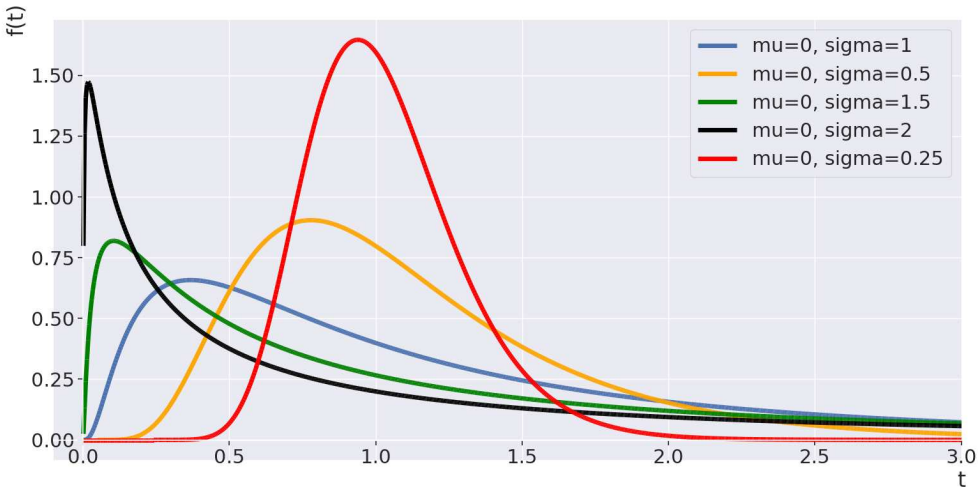


Figure 5.2: Lognormal distributions with different values for σ

5.2.1 Analytic expression of time-indexes

In order to be able to estimate the parameters t_0, μ, σ, we need to express the time-indexes analytically. First the velocity profile is considered to be a lognormal function weighted by D and shifted by t_0:

$$v(t; t_0, \mu, \sigma^2) = D\Lambda(t; t_0, \mu, \sigma^2) = \begin{cases} \frac{D}{\sigma\sqrt{2\pi}(t-t_0)} e^{-\frac{(\ln(t-t_0)-\mu)^2}{2\sigma^2}} & \text{if } t > t_0 \\ 0 & \text{elsewhere} \end{cases} \tag{5.1}$$

$$v(t; t_0, \mu, \sigma^2) = \begin{cases} \frac{D}{\sigma\sqrt{2\pi}(t-t_0)} e^{-\frac{k^2}{2}} & \text{if } t > t_0 \\ 0 & \text{elsewhere} \end{cases} \tag{5.2}$$

where $k = \frac{\ln(t-t_0)-\mu}{\sigma} \rightarrow \frac{dk}{dt} = \frac{1}{\sigma(t-t_0)}$.

The first lognormal derivative is given by:

$$\frac{dv(t; t_0, \mu, \sigma^2)}{dt} = -\frac{v(t; t_0, \mu, \sigma^2)}{\sigma(t-t_0)}(\sigma + k) \tag{5.3}$$

Therefore the maximum occurs when $\sigma + k = 0$, and can be expressed as:

$$\sigma + k = 0 \rightarrow k = \frac{\ln(t - t_0) - \mu}{\sigma} = -\sigma \rightarrow t_m = t_0 + e^{\mu - \sigma^2} \tag{5.4}$$

For the second time-derivative, it works similar:

$$\frac{d^2}{dt^2}(v(t; t_0, \mu, \sigma^2)) = \frac{v(t; t_0, \mu, \sigma^2)}{\sigma^2(t - t_0)^2}(k^2 + 3k\sigma + 2\sigma^2 - 1) \tag{5.5}$$

Hence the zeros of this function are given by:

$$k^2 + 3k\sigma + 2\sigma^2 - 1 = 0 \rightarrow k_{1,2} = \frac{-3\sigma \pm \sqrt{\sigma^2 + 4}}{2} \tag{5.6}$$

Then the inflexion points are:

$$t_{inf1,2} = t_0 + \exp\left\{\mu - \sigma(\frac{3\sigma + \sqrt{\sigma^2 + 4}}{2})\right\} = t_0 + \alpha_{inf1,2} \exp\left\{\mu - \sigma^2\right\} \tag{5.7}$$

with

$$\alpha_{inf1,2} = \exp\left\{-\sigma(\frac{\sigma + \sqrt{\sigma^2 + 4}}{2})\right\} = \exp\left\{-a_{inf1,2}\right\} \tag{5.8}$$

In order to estimate σ, two additional time-indexes are used, t_{min} and t_{max}. These are defined as:

$$I = [e^{\mu - 3\sigma}, e^{\mu + 3\sigma}] = [t_{min}, t_{max}] \tag{5.9}$$

so that I is the interval which covers 99.97% of the surface under a lognormal curve. Figure 5.3 shows a lognormal function with its derivatives and the time-indexes $t_{min}, t_{inf1}, t_m, t_{inf2}, t_{max}$ in that order.

5.2.2 Estimation of agonist parameters

When estimating the agonist parameters the original velocity profile is assumed to be a single lognormal distribution and not the difference of two individual profiles. The estimation of σ can

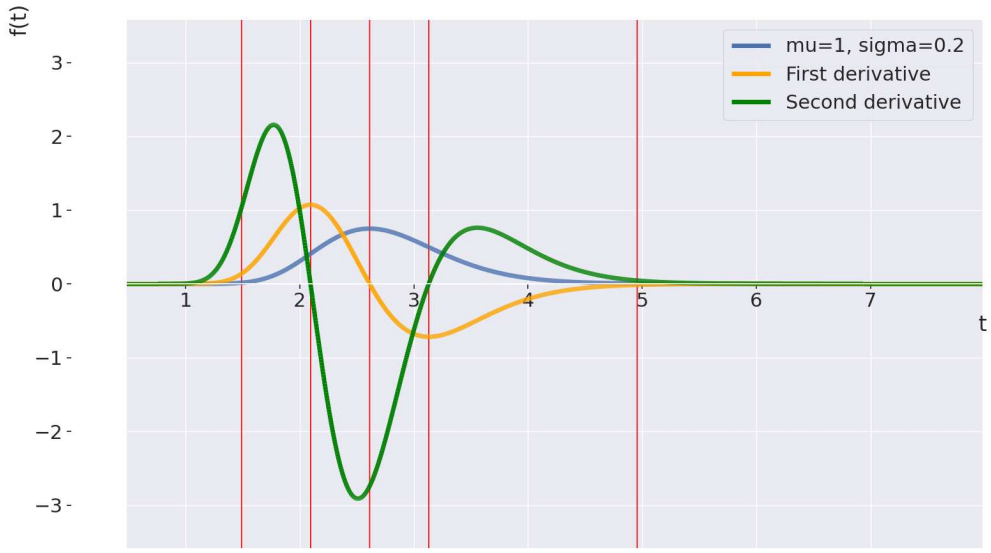


Figure 5.3: Time-indexes (red) used for parameter estimation of lognormal distribution (blue)

be done by using the Formulas 5.4 and 5.9:

$$t_{max} - t_{min} = e^{\mu}(e^{3\sigma} - e^{-3\sigma}) \Leftrightarrow e^{\mu} = \frac{t_{max} - t_{min}}{2\sinh(3\sigma)} \tag{5.10}$$

$$t_m - t_{min} = e^{\mu}(e^{-\sigma^2} - e^{-3\sigma}) \tag{5.11}$$

which results in solving the nonlinear equation:

$$F(\sigma) = \frac{t_{max} - t_{min}}{2\sinh(3\sigma)}(e^{-\sigma^2} - e^{-3\sigma}) - (t_m - t_{min}) = 0 \tag{5.12}$$

with the estimated value $\hat{\sigma}$ for σ, μ can be estimated by using the Formulas 5.7 and 5.8:

$$\begin{aligned} t_{inf2} - t_{inf1} &= (\hat{\alpha}_{inf2} - \hat{\alpha}_{inf1})e^{\hat{\mu}-\hat{\sigma}^2} \\ \Leftrightarrow \hat{\mu} &= \hat{\sigma}^2 + \ln\left(\frac{t_{inf2} - t_{inf1}}{\hat{\alpha}_{inf2} - \hat{\alpha}_{inf1}}\right) \end{aligned} \tag{5.13}$$

$\hat{t}_0$ is directly calculated with Formula 5.4:

$$\hat{t}_0 = t_m - e^{\hat{\mu}-\hat{\sigma}^2} \tag{5.14}$$

$\hat{D}$ is calculated with the maximum velocity $v_m = v(t_m)$:

$$\begin{aligned} v(t_m;\hat{t}_0,\hat{\mu},\hat{\sigma}^2) = D\Lambda(t_m;\hat{t}_0,\hat{\mu},\hat{\sigma}^2) = v_m &= \frac{D}{\hat{\sigma}\sqrt{2\pi}(t_m-\hat{t}_0)} e^{-\frac{(\ln(t_m-\hat{t}_0)-\hat{\mu})^2}{2\hat{\sigma}^2}} \\ v_m = \frac{D}{\hat{\sigma}\sqrt{2\pi}(t_m-\hat{t}_0)} e^{-\frac{(\hat{\mu}-\hat{\sigma}^2-\hat{\mu})^2}{2\hat{\sigma}^2}} &= \frac{D}{\hat{\sigma}\sqrt{2\pi}e^{\hat{\mu}-\hat{\sigma}^2}} e^{-\hat{\mu}+\frac{\hat{\sigma}^2}{2}} \\ \hat{D} &= v_m\hat{\sigma}\sqrt{2\pi}e^{\hat{\mu}+\frac{\hat{\sigma}^2}{2}} \end{aligned} \tag{5.15}$$

5.2.3 Estimation of antagonist parameters

The parameters for the agonist velocity profile were estimated considering the retrieved data $v(t)$ a single lognormal distribution. The parameters for the antagonist movement are then estimated by subtracting the calculated agonist profile from the original one. Note that t_0 is the same for agonist and antagonist. This time σ is estimated using $t_{inf1,2}$ instead of t_{min}, t_{max} and t_m:

$$\frac{t_{inf2}-t_0}{t_{inf1}-t_0} = e^{a_{inf1}-a_{inf2}} \tag{5.16}$$

When using the definition of $a_{inf1,2}$ in Formula 5.8, we get the following estimation:

$$\hat{\sigma} = \sqrt{\sqrt{\ln^2\left(\frac{t_{inf2}-t_0}{t_{inf1}-t_0}\right)+4}-2} \tag{5.17}$$

and finally:

$$\hat{D} = v_{m2}\hat{\sigma}\sqrt{2\pi}e^{\hat{\mu}-0.5\hat{\sigma}^2} \tag{5.18}$$

where v_{m2} is the maximum of the remaining velocity profile $v_2(t)$.

5.2.4 Robust XZERO-Estimation

In order to get more stable results for the parameters, different approaches are tested with the estimation of σ. In the previous subsections 5.2.3 and 5.2.2 σ was estimated in different ways. Subsection 5.2.2 used t_{min}, t_{max} and t_m, while subsection 5.2.3 used $t_{inf1,2}$. Since we have 5

different time-indexes and their corresponding velocity $v(t)$, there are more ways to express σ. Three of them were used, as they are defined in the Formulas 5.22, 5.23 and 5.24. Therefore we define the velocity at our time-indexes as:

$$v_i = \frac{D}{\sigma\sqrt{2\pi}} e^{-\mu} e^{a_i - \frac{a_i^2}{2\sigma^2}}, \qquad i \in \{1, 2, 3, 4, 5\} \tag{5.19}$$

with

$$a_1 = 3\sigma \tag{5.20a}$$
$$a_2 = 1.5\sigma^2 + \sigma\sqrt{0.25\sigma^2 + 1} \tag{5.20b}$$
$$a_3 = \sigma^2 \tag{5.20c}$$
$$a_4 = 1.5\sigma^2 - \sigma\sqrt{0.25\sigma^2 + 1} \tag{5.20d}$$
$$a_5 = -3\sigma \tag{5.20e}$$

and:

$$\beta_{ij} = \frac{v_i}{v_j} \tag{5.21}$$

Then we can express σ as:

$$\sigma = \sqrt{-2 - 2\ln(\beta_{23}) - \frac{1}{2\ln(\beta_{23})}} \tag{5.22}$$
$$= \sqrt{2\sqrt{1 + \ln^2(\beta_{42})} - 2} \tag{5.23}$$
$$= \sqrt{-2 - 2\ln(\beta_{43}) - \frac{1}{2\ln(\beta_{43})}} \tag{5.24}$$

The corresponding values for μ and D are still estimated with Formula 5.13 and 5.15, respectively. This allows to choose the parameters, so that the original velocity profile is fitted best.

5.2.5 Retrieval of time-indexes

The XZERO-algorithm explains how to calculate the parameters of the lognormal distribution, given the time of the relevant points. Thus in order to use the algorithm, these points must be extracted first. Since the original profile has too much noise the data is smoothed using

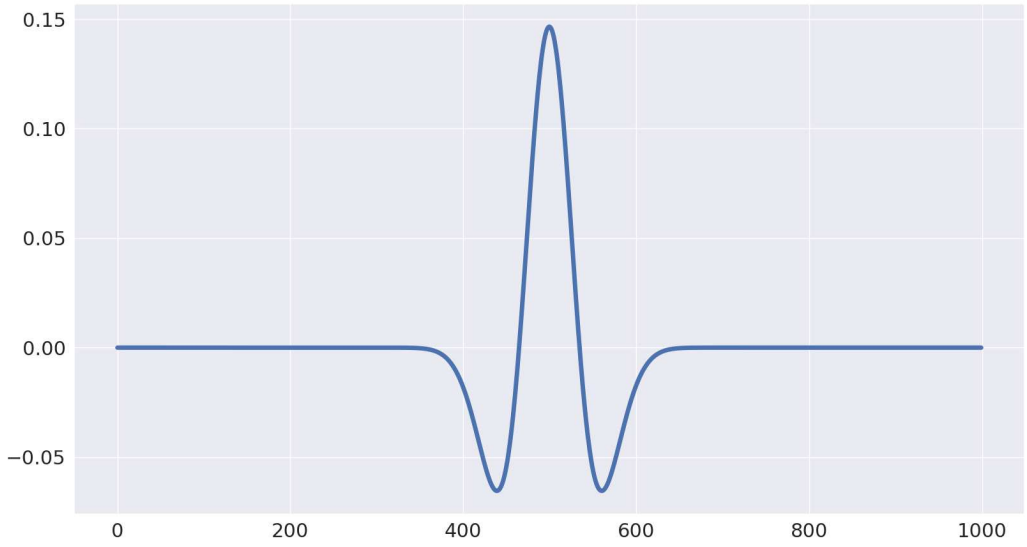


Figure 5.4: Ricker windows with a width of 35 over 1000 points

a continuous wavelet transforms with Ricker wavelets of different widths. Figure 5.4 shows such a wavelet with a width of 35 over 1000 points. A peak of the smoothed velocity was then considered a stroke. Since the wavelet increases maximums and decreases minimums the width of a peak was measured at 70% of its relative height. The data within this peak-width plus a predefined number of sample points before and after the retrieved width is then given to the XZERO-estimator. This estimator then applies again some smoothing, this time with a smaller window, in order to retrieve the time-indexes. This is done for the all different lengths of the wavelet, resulting in different estimations. By having these different wavelet lengths, different stroke sizes are modeled. For the final result a weighted sum of individual estimations is calculated, so that the error to the original velocity profile is minimized. Figure 5.5 shows a stroke together with the original velocity profile, the smoothed profiles and the fitted curves.

5.3 Lognormal neuromotor features

The XZERO-Algorithm attempts to fit a velocity profile. Therefore different approaches were tested for said profile: the absolute velocity, the horizontal and vertical velocity, as well as combinations of those. When using the XZERO-Algorithm on a task, it returns a set of parameters

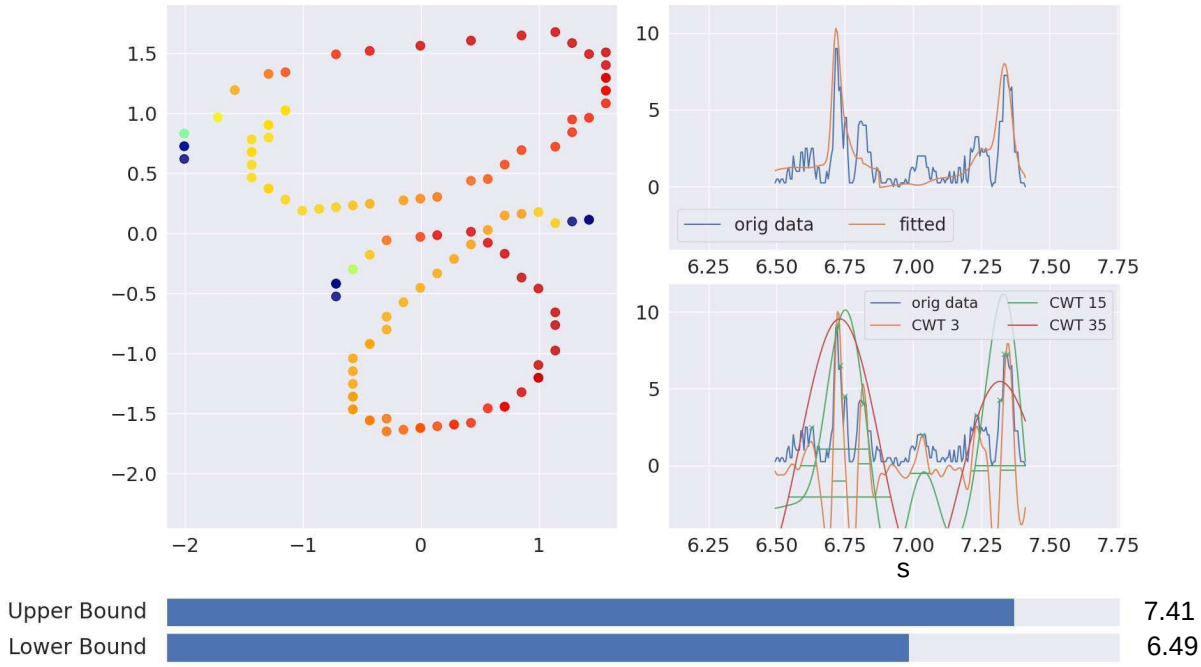


Figure 5.5: Number 8 of the *numbers* tasks (left) with the result of the XZERO-algorithm (top right) and the smoothed data with different window sizes (bottom right). Upper and lower bound refer the currently displayed time-section of the task in seconds. The task was performed by a PD patient

for each stroke. For the parameters μ, D, σ the mean, max and standard deviation were calculated for agonist and antagonist and used as features. Since a tremor would result in many small strokes, the ratio of big to small strokes was also taken into account. This was done by using the weights, which are calculated in the final estimation, as features.

5.4 Problems of XZERO-estimation

Using the features described in section 5.3 for the bi-class problem returns results close to random. This stands in contrast to [Imp19], where a combination of basic kinematic features and features from the XZERO-algorithm achieved an accuracy of 98%. Figure 5.6 shows a possible reason for that: often the estimation does not fit the original profile. However the section 5.3 provides several ways to estimate the parameters, so the resulting lognormal curve should be a good fit even if there is noise in the original data. That means, that when the resulting curve does not fit the data, the retrieved time-indexes were wrong. Such an error can have several reasons: first it is possible that the area where the algorithm is used upon is poorly estimated and does not represent

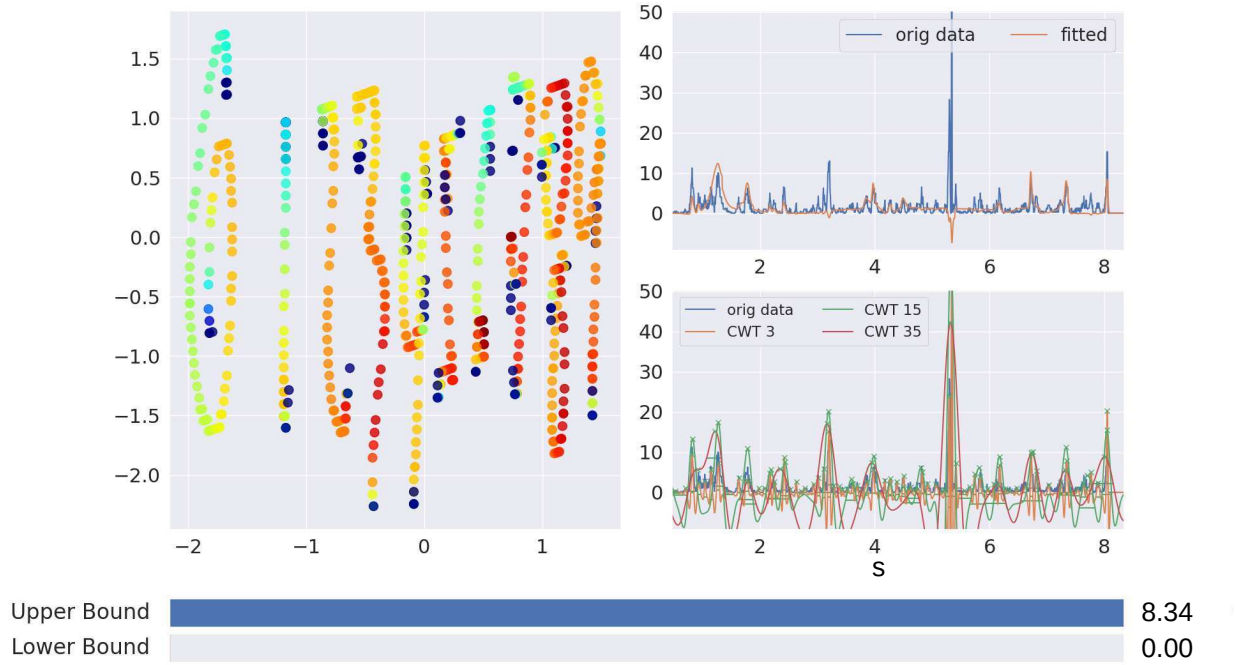


Figure 5.6: The complete sample of which a part was shown in Figure 5.5

a stroke, second the calculated indexes could be wrong either due to the smoothing or because of an atypical profile, e.g. when the stroke is only partially in the evaluated direction. Lastly the assumption that the velocity profile only consists of one single profile, which was made when estimating the agonist parameters, can also lead to an error. In the paper [Imp19], where using the XZERO-algorithm leads to an improvement over basic kinematic features, tasks with simple structures such as “lll” or “le le le” are used. Figure 5.7 shows a more drastic consequence of this error: When trying to optimize the weights for the estimations in this sample, the lowest error is achieved when setting them close to zero.

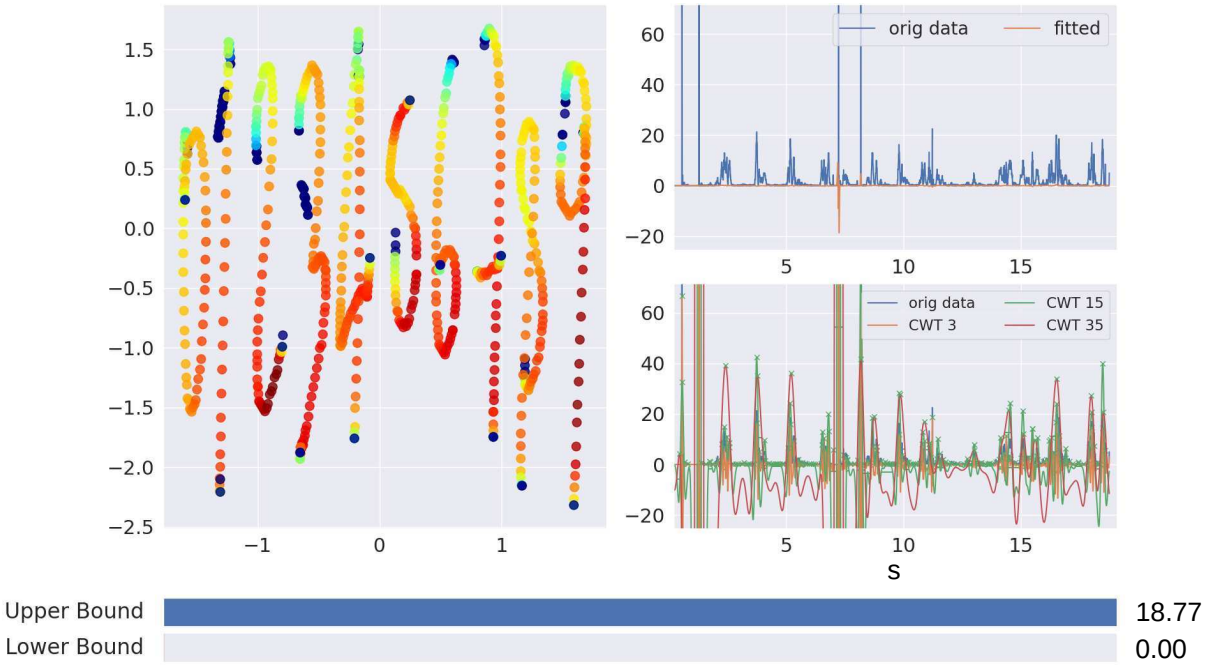


Figure 5.7: Numbers task performed by a HC subject. The weight for the lognormal model are optimized to zero.

Chapter 6

Summary & Conclusion

This thesis provided an overview of what Parkinson's Disease is and how current computer-aided diagnosis based on handwriting is done. The first goal was to test existing methods on the available data, to see how they perform in general and on individual tasks. As a result it was shown that simple figures, such as *circle* or *rectangles* achieve higher accuracies compared to more complex tasks, which consist of a variety of different strokes, such as *numbers* or *alphabet*. The accuracy already decreased for everything that is more complex than a *spiral*, which includes considerably simple shapes such as a *cube* or a *house*. Afterwards different combinations of tasks were evaluated. Combinations including both simple shapes and complex tasks, performed best. Some of those solutions achieved AUC-scores of over 0.9. After building a classifier for the bi-class problem, the more complex problem of evaluating the clinical score of the patient, was approached. Therefore, correlations between the MDS-UPDRS-III and the decision-boundary of the bi-class problem SVM were examined. After showing that no correlation between those two exists, an SVR was tested, but failed as well. Assuming that calculating the clinical score of a patient is too difficult, the problem was simplified by dividing the score into 4 classes. The results show an improvement over the previous SVR approach. However, the classifier only performed slightly better than random. After running these tests with the kinematic features, the next big goal was to find a new feature set, either as an addition to the kinematic features or as a completely new set. Therefore, the spectrograms of the trajectories were analyzed. The PSDs of the PD patients did have a peak at around 5 Hz, the HCs did not. Additionally, PD patients as well as HC subjects had a peak around 1 Hz in the PSD, where the height of the peak depends on the class of the subject. These observations were used to calculate a feature vector. Besides the trajectory, other signals were analyzed and tested for classification, either as a combination with the trajectory or as an individual signal, but none of them surpassed the performance of the trajectory. For the bi-

class problem the spectral features achieved the highest scores compared to all other classifiers presented in this thesis. AUC-values of over 0.95 were achieved with the tasks *house* and *signature*. In total 5 tasks had accuracies of over 90%. This time more complex tasks performed best, like *cube* or *house*. Tasks that were even more complex than those two, like *freewriting* or *alphabet*, only achieve low scores. But there are outliers, like the *signature* with an AUC of 0.955 and *numbers* with and AUC of 0.892. Just like with the kinematic features, the tasks were combined to see whether this leads to an improvement. Unlike previously, using multiple tasks for classification achieved lower scores than an individual task. Again, a disease severity evaluation was attempted, but neither the prediction of the clinical score nor the multi-class problem did show any improvements over the kinematic features. At last, it was tested whether the new features can be used as an addition to the kinematic ones. The results of the feature combinations show a decrease in all scores for all tasks. The last goal was to find a new feature set, based on modeling the velocity profile mathematically. Therefore, the Robust XZERO-algorithm was introduced as a method to estimate the parameters of a lognormal curve, so that the velocity profile is fitted. In order to detect strokes the velocity profile was smoothed with wavelets of different lengths. This resulted in multiple estimations consisting of strokes of different sizes. The final estimations was then calculated as the weighted sum over the previous estimations. Unfortunately the resulting curve often did not fit the original one. Nevertheless, an attempt was made using the retrieved parameters of the curves for a classification. The results were not satisfactory. The complete code from this thesis is available under https://gitlab.cs.fau.de/fi08deni/pd_analysis.git.

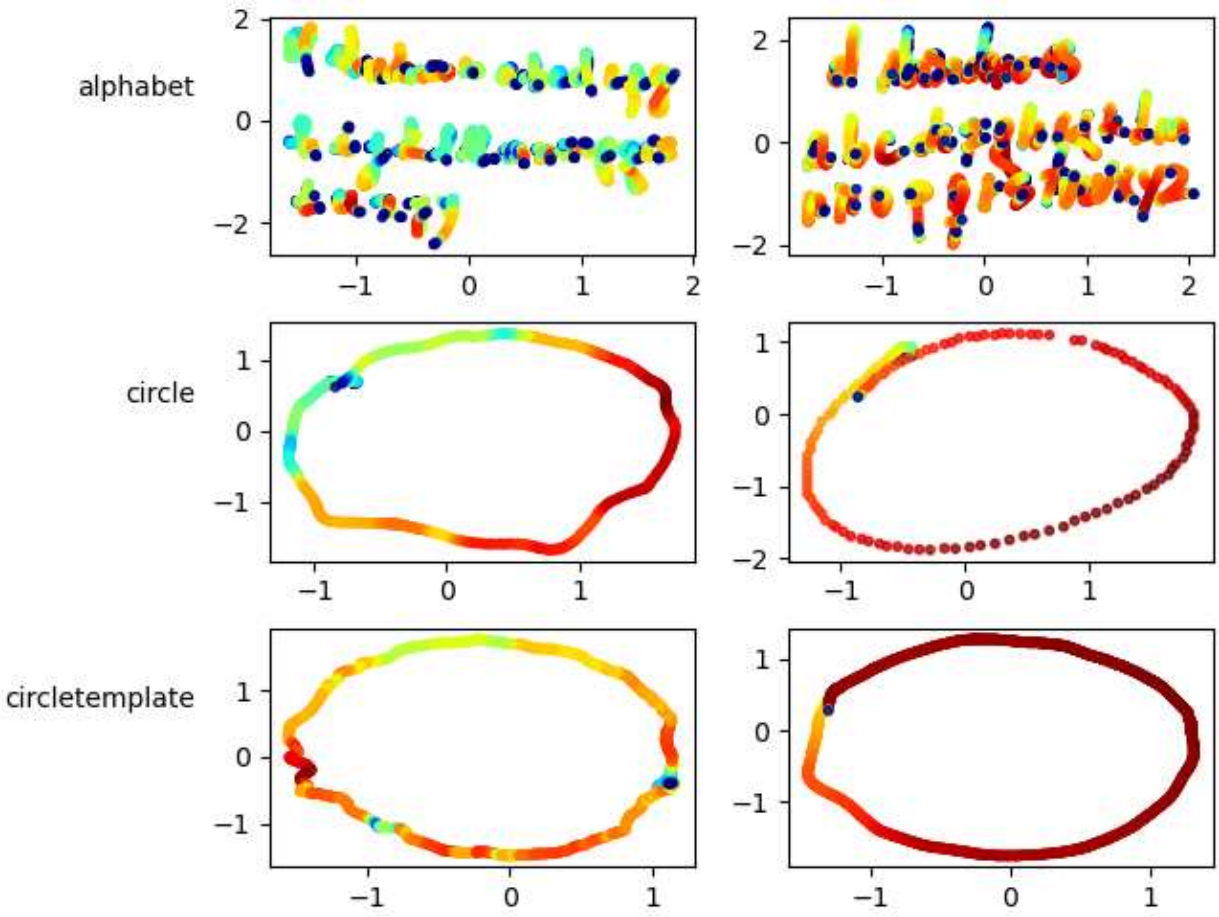
Chapter 7

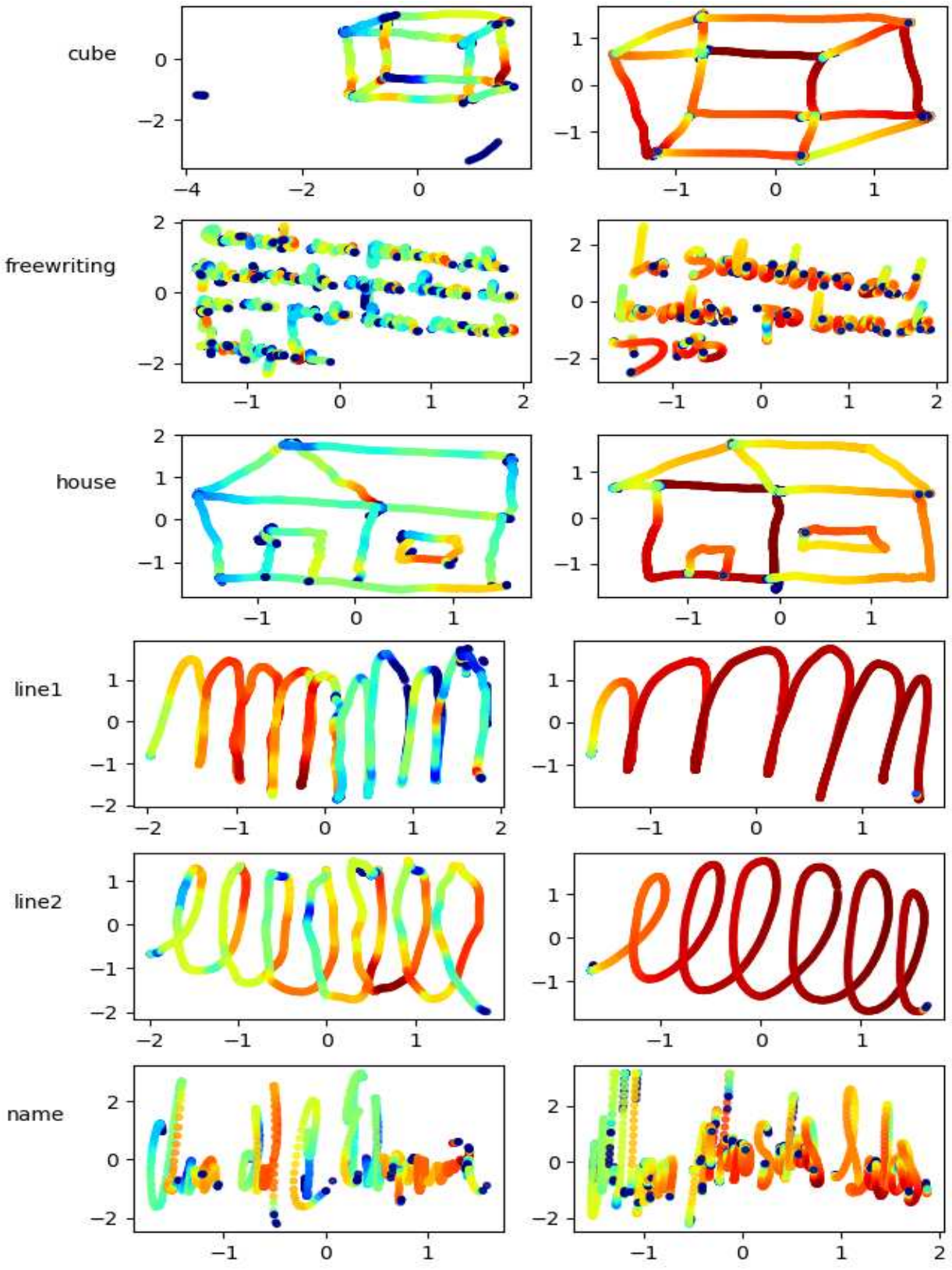
Future work

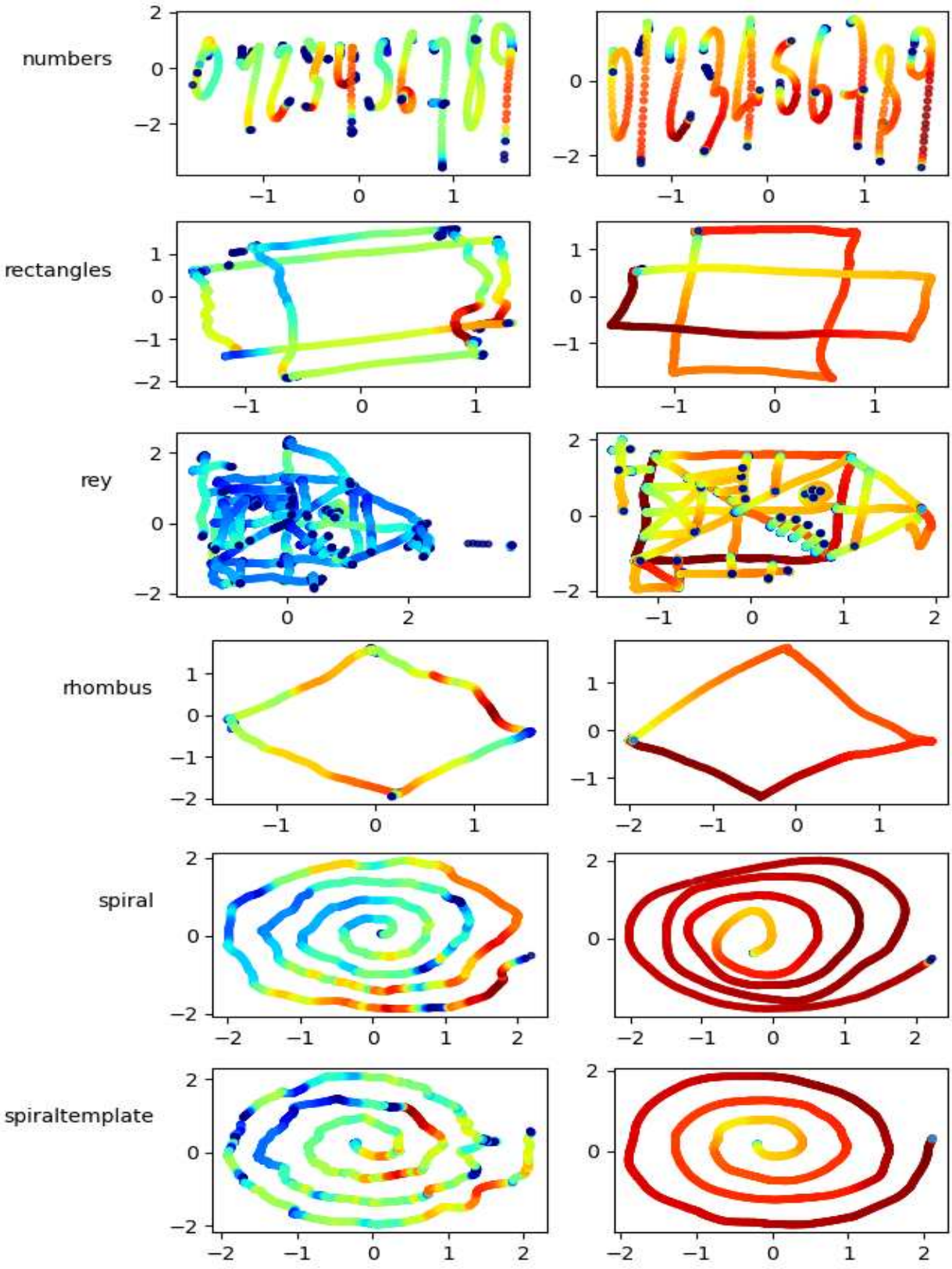
Merging the kinematic features of multiple tasks resulted in an improvement over an individual task. It was not tested whether there is also an improvement regarding the regression and multi-class problem. The spectral feature set, which was introduced in this thesis did achieve high scores for the bi-class problem. Even though it was shown that this set cannot be improved by combining different tasks or merging it with the kinematic feature set, the set only consists of ten features. It would be interesting to see whether task-specific features would be able to extend this set, like it was tested with the number of turns of the *spiral*. Furthermore, it remains open why the spectral features perform so well on *signature*, while *alphabet* and *freewriting* only achieve low scores, even though they share a lot of similarities. With the current explanation, which makes assumption based on the complexity of the tasks, the performance of *signature* and *numbers* cannot be explained. A lot of work can be done with the last part of the thesis, the modeling with lognormal distributions. The current implementation did not work because the extraction of the time-indexes was not sufficient. Therefore, two options exist: tests could be run with other more simple tasks, which only consists of a few strokes, or ideally the calculation of the areas, which are to be estimated, and the extraction of the time-indexes is improved.

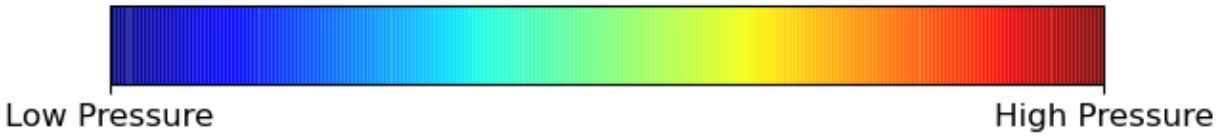
Appendix A

Chapter 2




cube
freewriting
house
line1
line2
name


numbers
rectangles
rey
rhombus
spiral
spiraltemplate


Low Pressure
High Pressure

Appendix B

Chapter 3

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, circle	76.9	88.6	77.4	0.822	0.849
alphabet, circletemplate	69.5	86.4	71.0	0.764	0.779
alphabet, cube	68.7	79.6	75.4	0.765	0.731
alphabet, freewriting	69.5	83.7	71.2	0.759	0.790
alphabet, house	67.3	85.4	65.8	0.734	0.762
alphabet, id	67.9	84.1	68.1	0.746	0.767
alphabet, line1	72.8	89.2	71.8	0.791	0.807
alphabet, line2	71.2	88.7	69.2	0.769	0.829
alphabet, name	71.0	79.9	78.9	0.787	0.706
alphabet, numbers	67.9	83.6	68.1	0.743	0.756
alphabet, rectangles	78.2	90.1	77.4	0.829	0.865
alphabet, rey	70.6	83.5	71.8	0.763	0.771
alphabet, rhombus	71.4	86.7	70.6	0.774	0.809
alphabet, signature	70.8	84.5	72.5	0.774	0.795
alphabet, spiral	72.6	87.4	71.1	0.777	0.832
alphabet, spiraltemplate	74.4	86.1	75.8	0.799	0.829
circle, circletemplate	71.8	88.6	72.2	0.785	0.824
circle, cube	79.1	87.4	84.3	0.853	0.835
circle, freewriting	76.3	87.6	78.5	0.820	0.845
circle, house	75.9	85.7	78.5	0.814	0.811
circle, id	75.9	86.4	78.7	0.819	0.807
circle, line1	75.1	87.2	78.0	0.809	0.823
circle, line2	80.4	92.3	80.7	0.856	0.858
circle, name	77.1	84.1	83.8	0.833	0.793
circle, numbers	80.2	88.9	82.3	0.849	0.865

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circle, rectangles	78.7	88.3	81.1	0.842	0.849
circle, rey	80.2	86.6	85.7	0.858	0.833
circle, rhombus	78.7	88.5	80.9	0.841	0.841
circle, signature	75.7	87.7	77.2	0.817	0.831
circle, spiral	78.3	87.8	81.2	0.841	0.818
circle, spiraltemplate	74.6	84.4	79.2	0.811	0.810
circletemplate, cube	55.6	59.5	52.6	0.524	0.757
circletemplate, freewriting	60.5	89.1	55.3	0.660	0.754
circletemplate, house	65.4	84.9	64.7	0.710	0.760
circletemplate, id	64.2	88.5	59.7	0.698	0.756
circletemplate, line1	51.0	51.2	49.8	0.457	0.805
circletemplate, line2	53.5	73.1	46.6	0.499	0.791
circletemplate, name	69.8	88.2	68.7	0.760	0.788
circletemplate, numbers	60.7	88.3	52.0	0.620	0.832
circletemplate, rectangles	73.7	87.4	76.3	0.803	0.821
circletemplate, rey	61.6	88.5	53.5	0.646	0.763
circletemplate, rhombus	68.6	89.0	66.9	0.747	0.805
circletemplate, signature	47.5	43.1	42.3	0.387	0.768
circletemplate, spiral	59.5	90.0	53.0	0.646	0.730
circletemplate, spiraltemplate	67.3	85.8	68.7	0.749	0.748
cube, freewriting	70.4	82.5	75.5	0.775	0.780
cube, house	66.9	81.4	70.1	0.745	0.719
cube, id	68.1	81.1	72.4	0.752	0.733
cube, line1	60.9	68.1	65.5	0.627	0.770
cube, line2	59.8	74.4	58.1	0.589	0.772
cube, name	71.6	80.9	79.7	0.791	0.748
cube, numbers	63.7	67.4	68.6	0.657	0.738
cube, rectangles	79.5	86.3	84.6	0.851	0.842
cube, rey	70.9	78.4	80.3	0.787	0.710
cube, rhombus	73.4	84.4	76.7	0.795	0.803
cube, signature	55.9	51.7	58.2	0.521	0.723
cube, spiral	79.1	87.1	83.3	0.847	0.840
cube, spiraltemplate	73.6	82.8	79.3	0.804	0.796
freewriting, house	77.0	84.8	82.2	0.830	0.825
freewriting, id	69.8	83.3	72.2	0.766	0.772
freewriting, line1	62.4	87.5	60.8	0.682	0.745
freewriting, line2	70.6	86.9	71.2	0.772	0.798
freewriting, name	66.6	82.3	69.5	0.739	0.732

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
freewriting, numbers	62.3	82.0	60.8	0.690	0.705
freewriting, rectangles	74.4	86.9	75.8	0.804	0.837
freewriting, rey	76.1	84.5	80.4	0.820	0.794
freewriting, rhombus	73.3	82.5	80.0	0.806	0.762
freewriting, signature	72.5	84.1	75.4	0.790	0.796
freewriting, spiral	73.1	85.7	74.2	0.787	0.808
freewriting, spiraltemplate	72.9	85.9	76.5	0.798	0.804
house, id	72.6	84.2	76.2	0.796	0.767
house, line1	65.1	86.7	62.5	0.719	0.748
house, line2	71.4	91.7	68.2	0.772	0.812
house, name	69.9	83.1	72.6	0.766	0.753
house, numbers	74.6	86.4	76.5	0.807	0.791
house, rectangles	73.7	85.7	75.9	0.799	0.812
house, rey	70.5	81.4	75.3	0.775	0.724
house, rhombus	75.8	88.2	75.9	0.812	0.829
house, signature	71.7	80.8	76.9	0.783	0.766
house, spiral	70.0	86.1	69.9	0.764	0.770
house, spiraltemplate	73.4	84.4	76.2	0.793	0.809
id, line1	70.4	88.9	69.2	0.770	0.799
id, line2	73.3	90.1	71.9	0.791	0.825
id, name	71.6	81.3	77.5	0.786	0.748
id, numbers	66.1	80.0	70.0	0.735	0.686
id, rectangles	71.2	83.4	74.9	0.783	0.756
id, rey	74.1	85.4	76.6	0.801	0.783
id, rhombus	73.6	87.8	73.7	0.794	0.816
id, signature	72.7	83.7	77.0	0.799	0.752
id, spiral	70.5	88.2	67.2	0.758	0.808
id, spiraltemplate	74.1	88.7	74.0	0.798	0.806
line1, line2	52.0	65.5	47.5	0.475	0.785
line1, name	68.1	85.6	69.1	0.749	0.770
line1, numbers	62.5	89.6	52.2	0.634	0.816
line1, rectangles	72.3	83.8	77.1	0.795	0.822
line1, rey	70.0	87.2	72.1	0.776	0.772
line1, rhombus	68.4	85.9	68.4	0.746	0.811
line1, signature	51.4	48.1	49.4	0.449	0.796
line1, spiral	66.4	86.1	64.8	0.725	0.762
line1, spiraltemplate	72.0	87.8	74.0	0.790	0.800
line2, name	67.6	86.1	68.5	0.747	0.765

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
line2, numbers	57.9	94.1	48.4	0.597	0.833
line2, rectangles	80.0	92.4	80.2	0.850	0.897
line2, rey	69.2	89.5	66.9	0.752	0.801
line2, rhombus	81.1	92.4	81.6	0.861	0.878
line2, signature	45.8	56.3	34.2	0.361	0.802
line2, spiral	72.0	90.3	71.0	0.783	0.819
line2, spiraltemplate	74.8	88.0	76.8	0.813	0.838
name, numbers	61.7	81.3	60.6	0.680	0.706
name, rectangles	73.2	82.7	79.6	0.802	0.787
name, rey	66.3	77.6	71.2	0.729	0.699
name, rhombus	70.1	82.8	73.7	0.768	0.788
name, signature	69.1	84.0	70.1	0.758	0.773
name, spiral	68.7	82.0	72.8	0.761	0.740
name, spiraltemplate	73.0	81.0	81.5	0.804	0.784
numbers, rectangles	74.3	87.0	76.1	0.805	0.837
numbers, rey	67.0	81.5	69.4	0.740	0.737
numbers, rhombus	74.8	86.2	77.0	0.810	0.825
numbers, signature	61.8	74.0	61.3	0.647	0.766
numbers, spiral	71.4	87.0	69.2	0.762	0.819
numbers, spiraltemplate	72.7	87.7	71.7	0.781	0.808
rectangles, rey	76.8	82.5	85.2	0.833	0.828
rectangles, rhombus	75.6	85.6	79.0	0.814	0.827
rectangles, signature	74.4	88.5	73.7	0.797	0.825
rectangles, spiral	77.0	88.3	77.9	0.822	0.859
rectangles, spiraltemplate	72.9	83.4	77.2	0.796	0.802
rey, rhombus	74.3	84.5	77.3	0.802	0.787
rey, signature	73.7	81.6	81.1	0.808	0.774
rey, spiral	70.5	85.5	71.7	0.770	0.776
rey, spiraltemplate	70.5	85.7	72.9	0.778	0.784
rhombus, signature	72.0	87.4	71.3	0.778	0.797
rhombus, spiral	72.4	86.4	74.1	0.792	0.816
rhombus, spiraltemplate	70.3	83.7	72.9	0.770	0.775
signature, spiral	73.0	87.0	73.8	0.791	0.818
signature, spiraltemplate	72.9	84.6	76.9	0.800	0.788
spiral, spiraltemplate	72.1	86.5	74.1	0.789	0.792
alphabet, circle, circletemplate	71.2	87.5	71.1	0.769	0.821
alphabet, circle, cube	79.4	86.1	85.8	0.854	0.837
alphabet, circle, freewriting	77.9	87.7	80.8	0.837	0.858

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, circle, house	77.7	86.7	81.2	0.834	0.832
alphabet, circle, id	78.4	86.9	80.7	0.831	0.846
alphabet, circle, line1	74.0	87.1	77.0	0.809	0.822
alphabet, circle, line2	77.5	89.6	79.7	0.834	0.865
alphabet, circle, name	78.0	82.9	88.1	0.846	0.823
alphabet, circle, numbers	78.2	88.2	80.0	0.834	0.861
alphabet, circle, rectangles	80.8	88.9	83.8	0.858	0.882
alphabet, circle, rey	79.2	86.6	83.4	0.844	0.836
alphabet, circle, rhombus	78.2	85.0	81.9	0.829	0.840
alphabet, circle, signature	77.4	89.6	78.5	0.831	0.867
alphabet, circle, spiral	77.5	88.8	78.7	0.832	0.841
alphabet, circle, spiraltemplate	76.8	84.8	80.8	0.821	0.855
alphabet, circletemplate, cube	76.6	83.7	83.6	0.829	0.834
alphabet, circletemplate, freewriting	69.6	85.5	70.8	0.755	0.779
alphabet, circletemplate, house	70.5	87.1	71.1	0.772	0.786
alphabet, circletemplate, id	67.2	88.3	64.2	0.730	0.785
alphabet, circletemplate, line1	71.1	88.3	71.3	0.778	0.808
alphabet, circletemplate, line2	76.7	90.3	75.5	0.816	0.869
alphabet, circletemplate, name	74.5	84.6	80.8	0.816	0.797
alphabet, circletemplate, numbers	73.5	88.6	73.4	0.789	0.827
alphabet, circletemplate, rectangles	75.5	89.5	75.8	0.808	0.852
alphabet, circletemplate, rey	70.8	88.4	70.6	0.767	0.836
alphabet, circletemplate, rhombus	74.0	88.7	73.5	0.792	0.826
alphabet, circletemplate, signature	72.3	87.6	73.0	0.787	0.804
alphabet, circletemplate, spiral	65.2	85.5	65.9	0.721	0.761
alphabet, circletemplate, spiraltemplate	72.8	84.8	77.5	0.798	0.785
alphabet, cube, freewriting	74.5	83.7	80.4	0.813	0.815
alphabet, cube, house	73.1	82.6	79.3	0.801	0.773
alphabet, cube, id	71.8	80.9	78.8	0.794	0.759
alphabet, cube, line1	73.5	80.6	82.2	0.808	0.760
alphabet, cube, line2	74.9	86.6	80.0	0.817	0.794
alphabet, cube, name	71.6	78.5	84.1	0.804	0.731
alphabet, cube, numbers	71.3	80.2	79.4	0.792	0.761
alphabet, cube, rectangles	79.8	85.9	85.7	0.851	0.862
alphabet, cube, rey	70.5	78.8	79.1	0.781	0.763
alphabet, cube, rhombus	76.0	84.5	80.9	0.821	0.823
alphabet, cube, signature	71.8	80.9	80.2	0.798	0.750
alphabet, cube, spiral	76.5	83.9	83.4	0.827	0.816

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, cube, spiraltemplate	72.0	78.5	81.9	0.793	0.785
alphabet, freewriting, house	71.6	84.2	74.6	0.782	0.806
alphabet, freewriting, id	72.8	85.3	75.8	0.794	0.802
alphabet, freewriting, line1	68.9	85.1	71.1	0.766	0.774
alphabet, freewriting, line2	72.5	87.8	73.5	0.789	0.812
alphabet, freewriting, name	73.4	80.7	83.0	0.812	0.783
alphabet, freewriting, numbers	71.4	85.2	72.6	0.775	0.814
alphabet, freewriting, rectangles	77.0	88.9	78.1	0.824	0.871
alphabet, freewriting, rey	72.2	84.2	76.1	0.792	0.800
alphabet, freewriting, rhombus	73.4	88.2	73.5	0.796	0.824
alphabet, freewriting, signature	73.2	85.2	76.0	0.794	0.820
alphabet, freewriting, spiral	74.2	87.2	75.7	0.804	0.826
alphabet, freewriting, spiraltemplate	76.0	84.3	80.5	0.816	0.834
alphabet, house, id	69.8	83.1	72.2	0.765	0.747
alphabet, house, line1	71.8	87.8	71.5	0.782	0.804
alphabet, house, line2	69.7	89.9	68.3	0.768	0.826
alphabet, house, name	69.7	79.3	77.5	0.776	0.722
alphabet, house, numbers	70.4	83.8	70.9	0.761	0.792
alphabet, house, rectangles	79.2	90.9	79.0	0.840	0.873
alphabet, house, rey	71.0	83.4	71.9	0.763	0.773
alphabet, house, rhombus	74.2	88.3	73.0	0.794	0.834
alphabet, house, signature	74.8	84.6	78.0	0.807	0.803
alphabet, house, spiral	69.5	84.2	69.0	0.751	0.796
alphabet, house, spiraltemplate	74.0	85.1	77.1	0.799	0.827
alphabet, id, line1	71.2	88.5	70.2	0.775	0.800
alphabet, id, line2	74.0	90.6	73.7	0.802	0.830
alphabet, id, name	75.0	83.0	83.2	0.822	0.754
alphabet, id, numbers	71.0	82.3	75.9	0.781	0.785
alphabet, id, rectangles	74.7	85.8	76.8	0.806	0.837
alphabet, id, rey	68.6	84.1	69.2	0.753	0.768
alphabet, id, rhombus	72.3	85.1	75.4	0.793	0.801
alphabet, id, signature	72.0	82.3	77.3	0.792	0.775
alphabet, id, spiral	72.9	88.3	71.7	0.786	0.810
alphabet, id, spiraltemplate	73.7	84.2	78.2	0.801	0.836
alphabet, line1, line2	74.8	90.4	73.6	0.801	0.851
alphabet, line1, name	70.1	80.1	79.8	0.786	0.748
alphabet, line1, numbers	71.2	86.9	71.4	0.777	0.807
alphabet, line1, rectangles	81.0	89.2	84.1	0.861	0.888

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, line1, rey	74.4	87.2	76.4	0.808	0.824
alphabet, line1, rhombus	70.7	88.4	71.5	0.779	0.819
alphabet, line1, signature	72.7	83.5	76.8	0.790	0.783
alphabet, line1, spiral	73.0	86.8	74.3	0.791	0.792
alphabet, line1, spiraltemplate	75.4	86.1	79.9	0.821	0.821
alphabet, line2, name	74.1	82.9	82.5	0.817	0.763
alphabet, line2, numbers	76.7	91.0	76.1	0.821	0.859
alphabet, line2, rectangles	86.1	92.5	88.0	0.899	0.926
alphabet, line2, rey	76.7	88.6	77.8	0.822	0.853
alphabet, line2, rhombus	79.4	89.3	82.0	0.847	0.867
alphabet, line2, signature	75.6	88.8	76.6	0.812	0.832
alphabet, line2, spiral	72.0	88.4	71.6	0.784	0.819
alphabet, line2, spiraltemplate	74.8	87.9	77.1	0.813	0.839
alphabet, name, numbers	71.9	81.0	78.3	0.789	0.769
alphabet, name, rectangles	76.5	85.6	81.6	0.828	0.834
alphabet, name, rey	71.2	80.5	78.4	0.788	0.731
alphabet, name, rhombus	72.3	82.2	80.1	0.801	0.770
alphabet, name, signature	72.2	80.0	80.9	0.800	0.741
alphabet, name, spiral	73.0	81.8	80.1	0.800	0.785
alphabet, name, spiraltemplate	74.0	83.2	79.2	0.804	0.796
alphabet, numbers, rectangles	80.0	90.5	81.2	0.851	0.878
alphabet, numbers, rey	71.6	81.8	76.4	0.782	0.796
alphabet, numbers, rhombus	75.2	89.8	72.9	0.799	0.843
alphabet, numbers, signature	71.0	85.3	72.0	0.774	0.794
alphabet, numbers, spiral	75.1	89.6	72.9	0.796	0.854
alphabet, numbers, spiraltemplate	76.8	87.9	78.3	0.820	0.867
alphabet, rectangles, rey	78.6	88.7	79.9	0.836	0.874
alphabet, rectangles, rhombus	80.1	88.8	81.3	0.844	0.887
alphabet, rectangles, signature	80.3	91.5	80.1	0.851	0.885
alphabet, rectangles, spiral	81.4	90.1	81.8	0.855	0.888
alphabet, rectangles, spiraltemplate	80.1	88.7	82.5	0.850	0.876
alphabet, rey, rhombus	72.4	84.5	74.5	0.784	0.799
alphabet, rey, signature	71.8	79.6	78.6	0.785	0.791
alphabet, rey, spiral	73.0	85.7	75.3	0.795	0.805
alphabet, rey, spiraltemplate	74.7	84.4	79.5	0.812	0.835
alphabet, rhombus, signature	72.6	87.2	71.8	0.780	0.826
alphabet, rhombus, spiral	73.8	85.5	74.8	0.789	0.827
alphabet, rhombus, spiraltemplate	77.2	85.2	81.8	0.828	0.839

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, signature, spiral	74.9	89.0	74.9	0.808	0.843
alphabet, signature, spiraltemplate	77.0	84.9	81.4	0.826	0.851
alphabet, spiral, spiraltemplate	73.8	86.9	73.6	0.788	0.841
circle, circletemplate, cube	76.7	84.9	84.3	0.837	0.812
circle, circletemplate, freewriting	74.2	87.4	75.6	0.800	0.825
circle, circletemplate, house	73.5	86.8	75.5	0.798	0.815
circle, circletemplate, id	68.9	83.6	72.3	0.766	0.760
circle, circletemplate, line1	73.8	86.7	77.2	0.804	0.793
circle, circletemplate, line2	75.3	89.2	75.6	0.811	0.852
circle, circletemplate, name	73.5	81.8	81.7	0.806	0.765
circle, circletemplate, numbers	75.1	86.6	78.5	0.817	0.813
circle, circletemplate, rectangles	76.4	87.9	80.1	0.832	0.819
circle, circletemplate, rey	72.8	84.9	77.0	0.795	0.774
circle, circletemplate, rhombus	74.7	89.2	76.6	0.809	0.820
circle, circletemplate, signature	70.1	85.6	71.8	0.770	0.776
circle, circletemplate, spiral	68.6	89.5	67.4	0.754	0.789
circle, circletemplate, spiraltemplate	70.1	83.0	75.2	0.775	0.767
circle, cube, freewriting	80.8	86.3	88.2	0.866	0.865
circle, cube, house	79.5	85.0	87.1	0.857	0.815
circle, cube, id	76.8	84.0	83.2	0.830	0.801
circle, cube, line1	76.7	85.3	84.1	0.838	0.767
circle, cube, line2	79.2	87.8	85.4	0.858	0.815
circle, cube, name	76.5	81.3	88.5	0.836	0.790
circle, cube, numbers	79.9	84.9	88.2	0.857	0.849
circle, cube, rectangles	82.4	87.3	88.6	0.877	0.862
circle, cube, rey	77.2	84.3	82.9	0.830	0.813
circle, cube, rhombus	79.2	84.0	87.4	0.851	0.829
circle, cube, signature	77.5	82.6	87.4	0.841	0.827
circle, cube, spiral	80.8	87.2	87.4	0.866	0.828
circle, cube, spiraltemplate	78.1	83.6	86.7	0.846	0.823
circle, freewriting, house	80.4	86.4	85.7	0.856	0.854
circle, freewriting, id	78.3	87.2	81.9	0.839	0.849
circle, freewriting, line1	75.7	86.8	79.5	0.824	0.813
circle, freewriting, line2	77.8	89.0	80.7	0.841	0.832
circle, freewriting, name	78.2	85.8	84.1	0.842	0.831
circle, freewriting, numbers	78.5	89.2	80.0	0.836	0.858
circle, freewriting, rectangles	82.4	89.7	85.6	0.872	0.881
circle, freewriting, rey	79.1	86.6	84.0	0.847	0.845

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circle, freewriting, rhombus	78.6	85.5	83.8	0.841	0.858
circle, freewriting, signature	76.1	88.6	77.3	0.820	0.847
circle, freewriting, spiral	76.0	87.9	78.7	0.825	0.829
circle, freewriting, spiraltemplate	79.0	84.6	85.3	0.843	0.855
circle, house, id	75.2	85.2	79.6	0.817	0.811
circle, house, line1	75.0	87.2	78.5	0.821	0.808
circle, house, line2	75.7	89.9	76.9	0.820	0.834
circle, house, name	75.7	81.3	84.6	0.822	0.790
circle, house, numbers	79.2	88.3	82.8	0.848	0.860
circle, house, rectangles	79.2	87.1	82.3	0.843	0.840
circle, house, rey	80.2	86.1	85.8	0.855	0.851
circle, house, rhombus	76.4	86.5	80.1	0.825	0.813
circle, house, signature	78.9	87.0	82.6	0.844	0.846
circle, house, spiral	77.3	84.6	83.3	0.835	0.799
circle, house, spiraltemplate	75.3	84.1	81.3	0.821	0.818
circle, id, line1	76.9	87.0	81.5	0.837	0.799
circle, id, line2	76.9	90.9	77.9	0.833	0.840
circle, id, name	77.7	82.9	85.9	0.839	0.829
circle, id, numbers	79.8	89.5	82.0	0.851	0.866
circle, id, rectangles	79.0	88.4	81.8	0.845	0.847
circle, id, rey	82.4	88.6	86.9	0.873	0.841
circle, id, rhombus	77.0	86.8	79.7	0.824	0.825
circle, id, signature	73.4	86.7	74.7	0.796	0.823
circle, id, spiral	76.4	87.0	78.4	0.821	0.830
circle, id, spiraltemplate	76.1	85.5	79.7	0.820	0.840
circle, line1, line2	75.0	88.9	76.4	0.815	0.824
circle, line1, name	75.7	82.0	87.2	0.834	0.767
circle, line1, numbers	76.7	88.0	79.9	0.832	0.823
circle, line1, rectangles	79.3	89.0	82.7	0.854	0.837
circle, line1, rey	77.8	85.9	83.6	0.841	0.800
circle, line1, rhombus	75.2	88.2	77.8	0.824	0.803
circle, line1, signature	71.4	86.3	75.7	0.788	0.784
circle, line1, spiral	75.5	88.2	78.3	0.819	0.834
circle, line1, spiraltemplate	76.5	86.7	81.9	0.834	0.800
circle, line2, name	77.4	84.9	86.7	0.849	0.781
circle, line2, numbers	79.1	91.1	80.7	0.852	0.856
circle, line2, rectangles	85.1	89.9	89.5	0.893	0.887
circle, line2, rey	78.3	88.3	81.4	0.842	0.828

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circle, line2, rhombus	81.7	90.4	84.1	0.867	0.877
circle, line2, signature	74.9	88.9	76.0	0.807	0.831
circle, line2, spiral	78.0	91.2	77.3	0.831	0.845
circle, line2, spiraltemplate	79.0	88.8	82.6	0.851	0.827
circle, name, numbers	77.5	86.0	83.2	0.840	0.804
circle, name, rectangles	77.5	82.0	87.2	0.840	0.812
circle, name, rey	75.6	84.0	82.0	0.822	0.794
circle, name, rhombus	78.2	84.8	85.9	0.846	0.810
circle, name, signature	75.1	82.2	83.4	0.820	0.805
circle, name, spiral	76.5	82.8	85.4	0.833	0.803
circle, name, spiraltemplate	74.6	80.5	84.3	0.815	0.800
circle, numbers, rectangles	81.3	88.6	84.4	0.861	0.860
circle, numbers, rey	81.0	88.1	84.6	0.859	0.846
circle, numbers, rhombus	82.1	88.2	85.3	0.864	0.870
circle, numbers, signature	76.1	86.7	78.0	0.816	0.836
circle, numbers, spiral	80.7	87.8	84.1	0.856	0.861
circle, numbers, spiraltemplate	78.4	85.3	82.3	0.828	0.850
circle, rectangles, rey	79.0	88.3	81.6	0.842	0.854
circle, rectangles, rhombus	79.2	86.2	83.9	0.845	0.852
circle, rectangles, signature	78.3	87.4	81.4	0.839	0.849
circle, rectangles, spiral	82.2	90.2	84.8	0.872	0.871
circle, rectangles, spiraltemplate	75.6	85.4	79.8	0.818	0.828
circle, rey, rhombus	79.9	86.7	85.3	0.854	0.821
circle, rey, signature	77.3	86.6	79.7	0.824	0.840
circle, rey, spiral	79.1	84.7	84.8	0.844	0.820
circle, rey, spiraltemplate	77.0	84.3	83.1	0.832	0.835
circle, rhombus, signature	74.8	87.4	74.9	0.800	0.818
circle, rhombus, spiral	76.4	87.8	78.3	0.821	0.828
circle, rhombus, spiraltemplate	78.2	86.7	82.2	0.838	0.848
circle, signature, spiral	76.3	87.8	77.9	0.822	0.843
circle, signature, spiraltemplate	78.1	86.3	82.1	0.836	0.849
circle, spiral, spiraltemplate	77.2	85.2	81.9	0.830	0.807
circletemplate, cube, freewriting	65.7	83.3	67.5	0.715	0.792
circletemplate, cube, house	77.3	85.9	83.2	0.839	0.838
circletemplate, cube, id	72.1	86.9	74.8	0.790	0.805
circletemplate, cube, line1	45.8	37.8	40.7	0.366	0.808
circletemplate, cube, line2	56.2	59.5	56.1	0.532	0.819
circletemplate, cube, name	70.4	84.5	77.1	0.775	0.806

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circletemplate, cube, numbers	57.7	62.0	56.7	0.547	0.818
circletemplate, cube, rectangles	79.7	86.1	87.2	0.861	0.840
circletemplate, cube, rey	68.7	90.3	63.9	0.718	0.812
circletemplate, cube, rhombus	73.8	84.1	79.5	0.799	0.830
circletemplate, cube, signature	53.2	46.3	54.8	0.486	0.759
circletemplate, cube, spiral	76.2	87.2	80.1	0.828	0.828
circletemplate, cube, spiraltemplate	74.0	81.8	84.7	0.820	0.820
circletemplate, freewriting, house	69.8	85.9	72.3	0.766	0.767
circletemplate, freewriting, id	67.0	89.4	64.3	0.732	0.766
circletemplate, freewriting, line1	65.5	90.9	59.0	0.701	0.791
circletemplate, freewriting, line2	70.9	91.4	68.4	0.766	0.850
circletemplate, freewriting, name	70.5	88.2	72.8	0.776	0.781
circletemplate, freewriting, numbers	68.3	90.7	63.5	0.736	0.796
circletemplate, freewriting, rectangles	74.3	88.1	77.2	0.814	0.800
circletemplate, freewriting, rey	61.8	89.5	53.2	0.648	0.760
circletemplate, freewriting, rhombus	64.8	88.7	60.5	0.701	0.799
circletemplate, freewriting, signature	65.0	88.9	63.0	0.710	0.776
circletemplate, freewriting, spiral	62.1	89.8	56.1	0.665	0.760
circletemplate, freewriting, spiraltemplate	67.3	83.3	72.1	0.752	0.758
circletemplate, house, id	67.4	84.9	68.8	0.745	0.756
circletemplate, house, line1	69.9	88.6	68.1	0.751	0.794
circletemplate, house, line2	71.0	89.6	68.4	0.768	0.822
circletemplate, house, name	73.2	84.6	78.4	0.802	0.812
circletemplate, house, numbers	75.8	87.5	77.4	0.814	0.851
circletemplate, house, rectangles	74.9	84.6	81.0	0.819	0.791
circletemplate, house, rey	65.9	84.9	66.7	0.733	0.761
circletemplate, house, rhombus	68.9	86.0	71.0	0.764	0.801
circletemplate, house, signature	68.8	84.2	72.0	0.759	0.761
circletemplate, house, spiral	64.0	84.8	62.6	0.690	0.749
circletemplate, house, spiraltemplate	70.9	84.9	74.4	0.775	0.783
circletemplate, id, line1	70.1	91.9	64.7	0.747	0.792
circletemplate, id, line2	73.9	91.5	70.4	0.788	0.850
circletemplate, id, name	69.7	82.7	75.6	0.771	0.760
circletemplate, id, numbers	69.1	91.9	64.4	0.748	0.785
circletemplate, id, rectangles	69.8	87.2	70.1	0.761	0.813
circletemplate, id, rey	65.9	87.8	61.6	0.704	0.784
circletemplate, id, rhombus	66.1	90.1	61.5	0.708	0.806
circletemplate, id, signature	63.0	87.7	61.1	0.693	0.773

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circletemplate, id, spiral	63.6	91.3	58.5	0.691	0.791
circletemplate, id, spiraltemplate	70.0	82.0	75.1	0.774	0.772
circletemplate, line1, line2	53.9	67.5	46.0	0.485	0.814
circletemplate, line1, name	72.1	90.2	71.5	0.774	0.830
circletemplate, line1, numbers	61.4	85.4	54.8	0.634	0.825
circletemplate, line1, rectangles	69.7	90.3	69.2	0.770	0.810
circletemplate, line1, rey	69.8	93.5	64.5	0.747	0.833
circletemplate, line1, rhombus	69.8	89.0	67.0	0.744	0.816
circletemplate, line1, signature	54.3	52.6	55.0	0.505	0.809
circletemplate, line1, spiral	66.4	88.9	63.0	0.709	0.762
circletemplate, line1, spiraltemplate	72.8	85.6	77.2	0.792	0.811
circletemplate, line2, name	71.0	90.1	67.8	0.751	0.842
circletemplate, line2, numbers	60.7	93.8	52.1	0.629	0.849
circletemplate, line2, rectangles	81.2	91.1	83.3	0.864	0.887
circletemplate, line2, rey	71.5	92.7	66.7	0.761	0.866
circletemplate, line2, rhombus	77.8	90.9	78.7	0.837	0.867
circletemplate, line2, signature	54.2	57.1	54.3	0.504	0.815
circletemplate, line2, spiral	66.6	93.5	58.8	0.704	0.825
circletemplate, line2, spiraltemplate	73.6	89.8	74.3	0.804	0.826
circletemplate, name, numbers	70.1	90.9	67.2	0.756	0.826
circletemplate, name, rectangles	76.6	86.7	81.9	0.834	0.822
circletemplate, name, rey	67.2	87.7	64.1	0.723	0.778
circletemplate, name, rhombus	73.8	87.3	75.9	0.798	0.840
circletemplate, name, signature	68.9	88.8	68.4	0.747	0.785
circletemplate, name, spiral	68.2	85.1	71.0	0.756	0.756
circletemplate, name, spiraltemplate	70.9	82.6	78.5	0.787	0.769
circletemplate, numbers, rectangles	76.1	90.4	76.3	0.818	0.858
circletemplate, numbers, rey	71.1	91.7	65.4	0.751	0. a
circletemplate, numbers, rhombus	74.8	88.3	74.8	0.801	0.864
circletemplate, numbers, signature	52.7	69.7	45.3	0.515	0.797
circletemplate, numbers, spiral	70.1	91.4	67.1	0.754	0.836
circletemplate, numbers, spiraltemplate	76.3	89.3	78.7	0.830	0.838
circletemplate, rectangles, rey	67.4	86.2	67.9	0.739	0.802
circletemplate, rectangles, rhombus	74.7	87.9	77.9	0.814	0.849
circletemplate, rectangles, signature	71.3	88.4	68.6	0.763	0.818
circletemplate, rectangles, spiral	72.5	86.9	75.1	0.794	0.800
circletemplate, rectangles, spiraltemplate	73.6	84.5	80.4	0.810	0.824
circletemplate, rey, rhombus	71.8	87.8	70.9	0.770	0.804

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circletemplate, rey, signature	64.5	88.8	58.3	0.686	0.777
circletemplate, rey, spiral	65.0	91.2	58.0	0.693	0.779
circletemplate, rey, spiraltemplate	71.5	84.8	75.8	0.782	0.802
circletemplate, rhombus, signature	67.8	88.3	65.3	0.736	0.802
circletemplate, rhombus, spiral	68.3	90.1	65.7	0.741	0.801
circletemplate, rhombus, spiraltemplate	73.4	85.0	78.2	0.804	0.808
circletemplate, signature, spiral	62.9	92.1	56.5	0.679	0.775
circletemplate, signature, spiraltemplate	72.2	84.8	76.8	0.792	0.789
circletemplate, spiral, spiraltemplate	67.2	85.5	69.6	0.751	0.749
cube, freewriting, house	73.8	80.8	82.8	0.808	0.786
cube, freewriting, id	73.4	83.0	80.3	0.809	0.782
cube, freewriting, line1	66.8	81.4	71.9	0.721	0.728
cube, freewriting, line2	65.8	82.3	68.3	0.707	0.810
cube, freewriting, name	71.6	81.2	79.0	0.787	0.773
cube, freewriting, numbers	69.0	82.3	76.4	0.767	0.783
cube, freewriting, rectangles	80.1	85.5	86.9	0.858	0.852
cube, freewriting, rey	76.2	84.3	82.7	0.824	0.808
cube, freewriting, rhombus	74.2	82.5	81.5	0.808	0.821
cube, freewriting, signature	67.4	72.7	76.6	0.733	0.757
cube, freewriting, spiral	78.2	86.6	83.1	0.841	0.855
cube, freewriting, spiraltemplate	77.5	84.4	84.8	0.842	0.842
cube, house, id	68.8	81.6	74.6	0.772	0.725
cube, house, line1	72.6	81.9	82.5	0.812	0.764
cube, house, line2	75.2	87.1	79.8	0.823	0.799
cube, house, name	74.7	82.6	83.9	0.826	0.748
cube, house, numbers	69.1	80.7	76.1	0.774	0.749
cube, house, rectangles	76.5	84.0	82.6	0.825	0.821
cube, house, rey	71.3	77.3	81.8	0.788	0.730
cube, house, rhombus	72.0	80.4	79.6	0.793	0.765
cube, house, signature	74.6	83.9	81.4	0.820	0.792
cube, house, spiral	75.9	85.6	80.0	0.821	0.809
cube, house, spiraltemplate	74.4	83.4	80.6	0.812	0.804
cube, id, line1	72.3	85.1	76.9	0.789	0.787
cube, id, line2	73.6	88.4	75.5	0.802	0.823
cube, id, name	72.7	78.3	81.8	0.795	0.736
cube, id, numbers	69.3	81.3	75.1	0.769	0.720
cube, id, rectangles	77.1	83.7	84.4	0.835	0.796
cube, id, rey	71.0	79.7	80.4	0.792	0.738

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
cube, id, rhombus	74.4	84.0	80.1	0.810	0.804
cube, id, signature	71.3	81.2	78.4	0.791	0.742
cube, id, spiral	77.1	87.9	79.2	0.826	0.836
cube, id, spiraltemplate	76.8	84.9	82.7	0.831	0.825
cube, line1, line2	53.3	51.3	52.5	0.482	0.768
cube, line1, name	70.2	82.0	76.6	0.769	0.777
cube, line1, numbers	55.4	53.1	53.1	0.507	0.815
cube, line1, rectangles	80.8	87.2	87.9	0.868	0.837
cube, line1, rey	68.6	85.6	73.1	0.753	0.765
cube, line1, rhombus	75.8	86.4	81.6	0.828	0.802
cube, line1, signature	55.7	51.2	54.0	0.504	0.797
cube, line1, spiral	74.0	83.9	80.5	0.808	0.805
cube, line1, spiraltemplate	74.3	85.1	80.4	0.817	0.806
cube, line2, name	70.5	86.6	74.4	0.766	0.808
cube, line2, numbers	58.4	64.0	58.8	0.567	0.820
cube, line2, rectangles	77.5	86.8	83.4	0.838	0.837
cube, line2, rey	70.8	88.6	71.1	0.763	0.823
cube, line2, rhombus	78.4	90.2	80.3	0.839	0.853
cube, line2, signature	49.6	45.9	45.7	0.423	0.751
cube, line2, spiral	72.5	88.5	74.0	0.787	0.835
cube, line2, spiraltemplate	77.5	84.4	86.0	0.848	0.815
cube, name, numbers	71.1	82.2	76.7	0.781	0.762
cube, name, rectangles	76.0	82.8	85.0	0.831	0.815
cube, name, rey	71.6	79.1	81.0	0.786	0.735
cube, name, rhombus	78.2	83.4	87.2	0.846	0.830
cube, name, signature	71.6	82.1	79.9	0.796	0.755
cube, name, spiral	75.2	85.0	81.3	0.824	0.800
cube, name, spiraltemplate	72.8	79.2	83.9	0.806	0.786
cube, numbers, rectangles	76.9	83.2	85.6	0.839	0.820
cube, numbers, rey	70.0	79.1	79.2	0.780	0.742
cube, numbers, rhombus	74.4	84.3	79.3	0.808	0.812
cube, numbers, signature	54.7	44.9	59.0	0.502	0.740
cube, numbers, spiral	81.3	88.1	84.9	0.858	0.870
cube, numbers, spiraltemplate	79.1	86.9	83.7	0.843	0.847
cube, rectangles, rey	76.4	81.0	86.6	0.830	0.826
cube, rectangles, rhombus	78.0	83.9	85.1	0.838	0.839
cube, rectangles, signature	76.6	85.1	82.7	0.832	0.811
cube, rectangles, spiral	81.3	88.4	84.9	0.861	0.870

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
cube, rectangles, spiraltemplate	77.0	84.4	83.6	0.833	0.827
cube, rey, rhombus	72.8	79.9	80.8	0.796	0.771
cube, rey, signature	72.3	80.6	80.2	0.797	0.761
cube, rey, spiral	77.5	86.0	82.7	0.838	0.820
cube, rey, spiraltemplate	76.4	82.7	83.7	0.825	0.799
cube, rhombus, signature	76.6	87.7	79.6	0.829	0.812
cube, rhombus, spiral	74.7	83.4	80.6	0.814	0.828
cube, rhombus, spiraltemplate	74.9	83.1	81.7	0.814	0.797
cube, signature, spiral	76.4	86.8	80.4	0.827	0.822
cube, signature, spiraltemplate	77.3	82.5	86.5	0.840	0.820
cube, spiral, spiraltemplate	78.4	85.1	85.1	0.845	0.855
freewriting, house, id	74.8	84.2	79.7	0.813	0.801
freewriting, house, line1	69.3	83.7	74.3	0.776	0.735
freewriting, house, line2	72.1	85.6	74.2	0.786	0.782
freewriting, house, name	74.7	80.8	84.4	0.818	0.792
freewriting, house, numbers	72.1	87.8	72.3	0.781	0.787
freewriting, house, rectangles	76.3	87.0	78.9	0.821	0.847
freewriting, house, rey	76.8	83.7	84.0	0.832	0.817
freewriting, house, rhombus	72.6	82.3	78.7	0.797	0.802
freewriting, house, signature	72.2	84.0	75.3	0.790	0.788
freewriting, house, spiral	73.8	86.4	75.4	0.799	0.809
freewriting, house, spiraltemplate	74.8	85.0	78.6	0.812	0.830
freewriting, id, line1	65.8	86.3	65.8	0.729	0.754
freewriting, id, line2	71.3	89.2	70.8	0.780	0.807
freewriting, id, name	73.3	84.1	78.2	0.804	0.783
freewriting, id, numbers	67.6	80.8	73.0	0.757	0.743
freewriting, id, rectangles	76.1	85.7	79.9	0.822	0.833
freewriting, id, rey	73.0	84.7	76.0	0.793	0.806
freewriting, id, rhombus	77.4	85.8	81.7	0.832	0.810
freewriting, id, signature	70.8	84.0	74.3	0.781	0.794
freewriting, id, spiral	73.6	88.0	73.0	0.790	0.825
freewriting, id, spiraltemplate	74.6	85.4	78.3	0.808	0.823
freewriting, line1, line2	65.9	89.6	63.4	0.725	0.779
freewriting, line1, name	64.4	82.3	64.9	0.686	0.745
freewriting, line1, numbers	68.8	86.0	69.8	0.754	0.790
freewriting, line1, rectangles	76.8	84.9	84.0	0.838	0.814
freewriting, line1, rey	66.6	87.2	68.4	0.742	0.757
freewriting, line1, rhombus	67.6	85.3	69.8	0.740	0.752

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
freewriting, line1, signature	67.9	86.6	69.7	0.755	0.770
freewriting, line1, spiral	68.3	84.5	70.7	0.751	0.753
freewriting, line1, spiraltemplate	71.7	82.4	79.5	0.798	0.753
freewriting, line2, name	66.1	88.9	63.6	0.714	0.795
freewriting, line2, numbers	68.6	88.8	67.4	0.747	0.818
freewriting, line2, rectangles	80.6	88.5	85.3	0.864	0.869
freewriting, line2, rey	73.0	89.1	74.1	0.793	0.828
freewriting, line2, rhombus	78.9	86.4	85.5	0.852	0.858
freewriting, line2, signature	65.4	89.1	61.8	0.706	0.782
freewriting, line2, spiral	71.4	87.5	73.9	0.790	0.807
freewriting, line2, spiraltemplate	74.2	88.5	76.5	0.810	0.821
freewriting, name, numbers	66.6	82.4	67.4	0.725	0.745
freewriting, name, rectangles	75.8	84.1	82.4	0.827	0.829
freewriting, name, rey	70.5	83.1	73.6	0.769	0.774
freewriting, name, rhombus	72.3	84.8	75.3	0.785	0.804
freewriting, name, signature	70.8	82.8	75.3	0.781	0.782
freewriting, name, spiral	72.4	81.9	79.2	0.794	0.789
freewriting, name, spiraltemplate	73.4	83.8	80.7	0.811	0.795
freewriting, numbers, rectangles	77.8	89.4	79.4	0.836	0.866
freewriting, numbers, rey	70.4	83.2	74.3	0.777	0.773
freewriting, numbers, rhombus	74.6	86.9	77.0	0.811	0.816
freewriting, numbers, signature	67.4	84.8	67.9	0.744	0.763
freewriting, numbers, spiral	70.3	86.7	68.9	0.762	0.801
freewriting, numbers, spiraltemplate	73.2	85.1	76.7	0.798	0.820
freewriting, rectangles, rey	76.4	85.8	80.2	0.824	0.833
freewriting, rectangles, rhombus	76.1	83.8	82.0	0.822	0.836
freewriting, rectangles, signature	75.1	88.0	74.8	0.803	0.847
freewriting, rectangles, spiral	75.6	88.3	76.4	0.811	0.855
freewriting, rectangles, spiraltemplate	74.3	84.7	78.1	0.808	0.822
freewriting, rey, rhombus	75.7	81.8	83.9	0.823	0.805
freewriting, rey, signature	71.8	85.3	74.8	0.791	0.800
freewriting, rey, spiral	74.6	85.9	76.1	0.799	0.809
freewriting, rey, spiraltemplate	74.0	83.5	78.6	0.799	0.826
freewriting, rhombus, signature	73.0	86.5	75.1	0.793	0.822
freewriting, rhombus, spiral	73.0	83.9	78.5	0.803	0.782
freewriting, rhombus, spiraltemplate	78.0	84.5	85.3	0.842	0.831
freewriting, signature, spiral	73.6	90.1	70.9	0.787	0.822
freewriting, signature, spiraltemplate	78.0	90.3	78.7	0.833	0.862

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
freewriting, spiral, spiraltemplate	75.0	83.7	80.1	0.813	0.805
house, id, line1	70.0	88.2	68.7	0.765	0.791
house, id, line2	73.7	94.2	69.7	0.794	0.839
house, id, name	74.1	82.0	82.3	0.817	0.744
house, id, numbers	73.8	83.3	79.6	0.812	0.766
house, id, rectangles	74.1	84.6	78.3	0.807	0.824
house, id, rey	74.9	84.8	80.0	0.816	0.812
house, id, rhombus	77.1	86.6	78.7	0.817	0.840
house, id, signature	72.8	82.3	78.3	0.797	0.771
house, id, spiral	76.3	89.4	76.3	0.820	0.837
house, id, spiraltemplate	77.8	86.6	81.3	0.832	0.839
house, line1, line2	69.2	92.9	65.3	0.755	0.815
house, line1, name	71.9	84.9	77.1	0.794	0.772
house, line1, numbers	71.0	88.0	71.7	0.779	0.792
house, line1, rectangles	75.7	87.7	79.4	0.829	0.818
house, line1, rey	72.0	84.7	76.0	0.792	0.744
house, line1, rhombus	71.1	87.9	71.8	0.780	0.805
house, line1, signature	67.6	83.3	68.3	0.738	0.763
house, line1, spiral	68.3	87.3	67.3	0.744	0.779
house, line1, spiraltemplate	69.1	83.6	73.7	0.771	0.783
house, line2, name	70.1	83.8	77.6	0.790	0.789
house, line2, numbers	79.4	93.9	77.6	0.844	0.849
house, line2, rectangles	76.2	91.0	75.6	0.821	0.849
house, line2, rey	70.2	92.5	66.6	0.758	0.817
house, line2, rhombus	77.0	91.9	75.5	0.822	0.847
house, line2, signature	74.0	91.0	73.4	0.801	0.826
house, line2, spiral	71.3	89.5	70.3	0.780	0.791
house, line2, spiraltemplate	76.2	90.1	77.2	0.825	0.835
house, name, numbers	70.2	81.4	76.4	0.776	0.753
house, name, rectangles	73.2	82.7	78.1	0.796	0.812
house, name, rey	70.9	81.4	75.6	0.776	0.736
house, name, rhombus	74.0	85.1	78.5	0.806	0.797
house, name, signature	71.9	82.2	78.5	0.796	0.752
house, name, spiral	72.8	82.0	79.5	0.801	0.773
house, name, spiraltemplate	74.2	82.1	82.6	0.816	0.815
house, numbers, rectangles	73.8	87.0	74.2	0.796	0.834
house, numbers, rey	71.4	79.8	79.4	0.785	0.767
house, numbers, rhombus	76.8	89.5	76.8	0.820	0.839

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
house, numbers, signature	71.6	83.2	74.7	0.781	0.779
house, numbers, spiral	73.9	88.9	72.6	0.791	0.823
house, numbers, spiraltemplate	78.3	86.5	81.6	0.834	0.859
house, rectangles, rey	74.6	84.9	78.2	0.804	0.805
house, rectangles, rhombus	75.6	87.5	76.3	0.809	0.844
house, rectangles, signature	77.2	90.5	76.1	0.822	0.848
house, rectangles, spiral	77.2	90.4	76.1	0.819	0.849
house, rectangles, spiraltemplate	74.2	85.0	76.5	0.798	0.828
house, rey, rhombus	73.5	83.9	77.9	0.801	0.801
house, rey, signature	76.0	85.2	80.9	0.825	0.817
house, rey, spiral	73.1	84.6	76.2	0.794	0.797
house, rey, spiraltemplate	74.4	82.5	80.5	0.808	0.797
house, rhombus, signature	75.9	84.8	80.6	0.820	0.809
house, rhombus, spiral	72.3	86.4	73.0	0.785	0.803
house, rhombus, spiraltemplate	74.9	85.5	79.1	0.817	0.831
house, signature, spiral	72.4	87.6	72.0	0.784	0.813
house, signature, spiraltemplate	77.4	85.6	82.7	0.833	0.854
house, spiral, spiraltemplate	73.9	87.7	74.7	0.796	0.818
id, line1, line2	74.2	91.1	72.6	0.801	0.830
id, line1, name	72.8	83.5	79.7	0.803	0.761
id, line1, numbers	69.9	89.8	67.7	0.762	0.795
id, line1, rectangles	75.5	89.1	77.5	0.818	0.835
id, line1, rey	77.0	88.6	79.6	0.832	0.825
id, line1, rhombus	69.0	90.6	65.6	0.745	0.824
id, line1, signature	69.3	88.6	68.2	0.760	0.808
id, line1, spiral	72.1	89.4	72.0	0.791	0.789
id, line1, spiraltemplate	75.3	87.8	78.0	0.814	0.811
id, line2, name	71.0	83.2	75.8	0.777	0.778
id, line2, numbers	73.8	90.3	73.2	0.803	0.825
id, line2, rectangles	79.7	90.8	80.8	0.850	0.871
id, line2, rey	76.5	92.8	73.9	0.816	0.853
id, line2, rhombus	78.7	91.3	78.8	0.841	0.873
id, line2, signature	69.7	89.8	69.8	0.775	0.802
id, line2, spiral	76.7	90.5	76.9	0.828	0.838
id, line2, spiraltemplate	74.5	87.1	77.7	0.812	0.825
id, name, numbers	67.6	81.4	72.9	0.753	0.724
id, name, rectangles	73.6	82.7	80.8	0.809	0.797
id, name, rey	71.4	81.5	78.1	0.789	0.783

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
id, name, rhombus	72.7	82.1	78.7	0.791	0.795
id, name, signature	73.3	81.9	79.9	0.799	0.779
id, name, spiral	73.0	82.9	77.4	0.791	0.797
id, name, spiraltemplate	73.5	82.3	79.5	0.800	0.785
id, numbers, rectangles	75.3	83.9	80.5	0.812	0.818
id, numbers, rey	66.7	80.6	70.4	0.743	0.723
id, numbers, rhombus	70.6	84.4	72.4	0.768	0.783
id, numbers, signature	69.5	82.2	72.2	0.760	0.756
id, numbers, spiral	75.1	90.1	73.2	0.801	0.841
id, numbers, spiraltemplate	74.0	85.3	77.5	0.805	0.811
id, rectangles, rey	75.1	81.5	83.1	0.817	0.814
id, rectangles, rhombus	80.4	88.4	83.2	0.854	0.867
id, rectangles, signature	72.3	85.5	74.0	0.785	0.802
id, rectangles, spiral	75.4	88.7	74.5	0.803	0.847
id, rectangles, spiraltemplate	76.8	83.9	83.1	0.828	0.831
id, rey, rhombus	76.1	86.0	78.6	0.817	0.824
id, rey, signature	74.9	83.5	80.4	0.814	0.785
id, rey, spiral	74.0	85.8	75.7	0.797	0.814
id, rey, spiraltemplate	76.3	86.3	79.7	0.818	0.846
id, rhombus, signature	70.6	85.9	72.1	0.773	0.794
id, rhombus, spiral	76.1	88.5	76.4	0.813	0.845
id, rhombus, spiraltemplate	78.7	86.4	83.5	0.845	0.841
id, signature, spiral	71.3	86.4	71.2	0.775	0.787
id, signature, spiraltemplate	73.3	84.0	78.6	0.805	0.784
id, spiral, spiraltemplate	76.1	85.4	80.1	0.820	0.828
line1, line2, name	67.3	89.3	66.1	0.737	0.800
line1, line2, numbers	55.8	82.2	47.5	0.555	0.839
line1, line2, rectangles	79.5	91.2	80.7	0.852	0.881
line1, line2, rey	67.9	88.3	66.8	0.744	0.798
line1, line2, rhombus	75.4	91.0	74.5	0.809	0.857
line1, line2, signature	44.8	40.0	33.8	0.326	0.796
line1, line2, spiral	68.3	89.9	66.9	0.756	0.799
line1, line2, spiraltemplate	74.8	87.2	77.8	0.812	0.814
line1, name, numbers	69.6	85.5	71.2	0.764	0.786
line1, name, rectangles	75.0	84.5	82.9	0.829	0.797
line1, name, rey	68.9	86.5	71.9	0.768	0.759
line1, name, rhombus	72.6	87.6	74.0	0.789	0.802
line1, name, signature	69.5	87.7	72.1	0.768	0.798

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Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
line1, name, spiral	69.1	82.7	74.9	0.770	0.726
line1, name, spiraltemplate	72.5	83.4	80.0	0.802	0.790
line1, numbers, rectangles	77.1	89.4	79.5	0.834	0.860
line1, numbers, rey	71.9	87.1	74.8	0.788	0.802
line1, numbers, rhombus	71.9	89.2	72.2	0.784	0.836
line1, numbers, signature	61.5	79.8	58.3	0.632	0.790
line1, numbers, spiral	70.6	86.8	71.9	0.777	0.794
line1, numbers, spiraltemplate	73.3	88.6	73.6	0.794	0.834
line1, rectangles, rey	71.6	84.4	76.6	0.793	0.793
line1, rectangles, rhombus	76.0	86.7	80.3	0.824	0.845
line1, rectangles, signature	77.1	88.3	81.2	0.836	0.853
line1, rectangles, spiral	79.0	89.4	82.9	0.852	0.858
line1, rectangles, spiraltemplate	75.5	83.9	82.2	0.824	0.838
line1, rey, rhombus	70.3	86.0	71.7	0.769	0.794
line1, rey, signature	69.7	89.5	69.0	0.762	0.810
line1, rey, spiral	70.2	84.5	73.5	0.773	0.759
line1, rey, spiraltemplate	75.8	87.6	78.8	0.823	0.833
line1, rhombus, signature	71.3	87.1	71.3	0.776	0.799
line1, rhombus, spiral	66.9	87.7	66.3	0.739	0.776
line1, rhombus, spiraltemplate	74.7	87.8	78.6	0.822	0.797
line1, signature, spiral	69.5	86.9	70.6	0.766	0.758
line1, signature, spiraltemplate	74.0	85.6	80.0	0.816	0.790
line1, spiral, spiraltemplate	73.1	86.5	77.6	0.804	0.814
line2, name, numbers	70.1	89.1	67.0	0.747	0.825
line2, name, rectangles	79.3	88.3	84.3	0.852	0.869
line2, name, rey	70.3	86.8	72.2	0.771	0.770
line2, name, rhombus	77.1	88.5	81.4	0.838	0.848
line2, name, signature	67.7	84.7	70.5	0.741	0.751
line2, name, spiral	71.5	86.6	75.2	0.790	0.778
line2, name, spiraltemplate	73.0	82.5	81.7	0.811	0.785
line2, numbers, rectangles	81.7	92.0	83.2	0.869	0.901
line2, numbers, rey	76.5	93.2	73.4	0.812	0.875
line2, numbers, rhombus	81.4	91.7	83.2	0.867	0.885
line2, numbers, signature	51.6	81.0	39.3	0.491	0.779
line2, numbers, spiral	76.5	91.6	75.3	0.821	0.841
line2, numbers, spiraltemplate	77.8	89.2	79.4	0.834	0.861
line2, rectangles, rey	75.9	90.2	76.2	0.818	0.874
line2, rectangles, rhombus	82.5	90.9	85.1	0.876	0.884

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
line2, rectangles, signature	80.9	90.0	82.8	0.859	0.882
line2, rectangles, spiral	81.1	90.6	82.9	0.861	0.881
line2, rectangles, spiraltemplate	80.5	87.1	86.3	0.862	0.870
line2, rey, rhombus	78.0	90.8	78.9	0.835	0.863
line2, rey, signature	71.0	91.1	69.9	0.769	0.840
line2, rey, spiral	70.4	89.0	70.3	0.770	0.811
line2, rey, spiraltemplate	76.5	86.8	80.0	0.825	0.859
line2, rhombus, signature	78.1	91.4	78.7	0.840	0.864
line2, rhombus, spiral	77.8	92.2	77.3	0.836	0.864
line2, rhombus, spiraltemplate	79.6	90.7	81.6	0.851	0.881
line2, signature, spiral	70.0	91.4	66.5	0.756	0.823
line2, signature, spiraltemplate	73.8	87.5	77.5	0.813	0.824
line2, spiral, spiraltemplate	74.9	87.6	78.0	0.813	0.838
name, numbers, rectangles	71.1	85.5	73.9	0.781	0.793
name, numbers, rey	68.8	84.0	70.2	0.753	0.768
name, numbers, rhombus	70.5	85.2	73.7	0.771	0.797
name, numbers, signature	69.5	83.6	71.5	0.754	0.773
name, numbers, spiral	68.1	83.0	69.1	0.740	0.785
name, numbers, spiraltemplate	70.7	79.3	79.9	0.786	0.785
name, rectangles, rey	75.2	85.1	79.7	0.812	0.816
name, rectangles, rhombus	76.2	87.1	79.4	0.823	0.838
name, rectangles, signature	73.1	83.5	77.9	0.797	0.788
name, rectangles, spiral	75.7	87.3	77.9	0.812	0.836
name, rectangles, spiraltemplate	71.5	82.3	76.0	0.783	0.768
name, rey, rhombus	68.6	82.1	72.0	0.756	0.768
name, rey, signature	73.9	83.1	79.3	0.804	0.794
name, rey, spiral	69.8	79.0	76.5	0.766	0.764
name, rey, spiraltemplate	74.8	82.4	81.8	0.813	0.824
name, rhombus, signature	74.0	85.2	77.1	0.799	0.821
name, rhombus, spiral	74.0	83.3	79.7	0.805	0.812
name, rhombus, spiraltemplate	74.1	84.4	79.5	0.807	0.816
name, signature, spiral	71.3	83.6	75.6	0.781	0.785
name, signature, spiraltemplate	72.8	82.3	78.7	0.797	0.800
name, spiral, spiraltemplate	72.9	81.9	79.3	0.795	0.788
numbers, rectangles, rey	72.7	83.6	75.6	0.786	0.821
numbers, rectangles, rhombus	78.9	86.8	82.5	0.840	0.859
numbers, rectangles, signature	72.5	88.1	70.2	0.776	0.826
numbers, rectangles, spiral	81.2	93.2	79.0	0.850	0.891

Continued on next page

Table B.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
numbers, rectangles, spiraltemplate	75.6	87.4	76.3	0.808	0.842
numbers, rey, rhombus	76.2	86.3	78.7	0.818	0.837
numbers, rey, signature	68.5	80.0	72.4	0.750	0.768
numbers, rey, spiral	73.6	84.7	75.7	0.788	0.829
numbers, rey, spiraltemplate	77.1	87.5	78.6	0.825	0.835
numbers, rhombus, signature	71.7	88.2	69.8	0.771	0.808
numbers, rhombus, spiral	75.3	87.4	76.6	0.806	0.844
numbers, rhombus, spiraltemplate	77.5	87.5	80.2	0.832	0.851
numbers, signature, spiral	70.9	88.4	68.4	0.758	0.837
numbers, signature, spiraltemplate	76.4	87.9	77.9	0.821	0.841
numbers, spiral, spiraltemplate	73.4	85.8	75.2	0.793	0.810
rectangles, rey, rhombus	76.3	86.1	80.8	0.825	0.834
rectangles, rey, signature	75.1	87.2	76.0	0.806	0.826
rectangles, rey, spiral	78.3	87.7	81.5	0.839	0.855
rectangles, rey, spiraltemplate	73.9	85.3	77.4	0.802	0.833
rectangles, rhombus, signature	77.9	87.3	80.5	0.832	0.842
rectangles, rhombus, spiral	75.9	84.9	81.1	0.822	0.831
rectangles, rhombus, spiraltemplate	77.4	83.5	83.8	0.831	0.850
rectangles, signature, spiral	78.3	88.9	78.8	0.830	0.874
rectangles, signature, spiraltemplate	75.8	84.7	80.5	0.818	0.845
rectangles, spiral, spiraltemplate	77.6	85.5	82.0	0.832	0.849
rey, rhombus, signature	74.5	83.8	78.6	0.803	0.814
rey, rhombus, spiral	77.5	84.6	82.8	0.833	0.816
rey, rhombus, spiraltemplate	74.1	84.8	78.7	0.805	0.820
rey, signature, spiral	72.0	86.3	73.5	0.787	0.823
rey, signature, spiraltemplate	76.1	85.6	80.2	0.820	0.839
rey, spiral, spiraltemplate	73.3	84.5	76.3	0.794	0.811
rhombus, signature, spiral	74.8	88.2	76.3	0.808	0.828
rhombus, signature, spiraltemplate	78.0	86.3	82.3	0.835	0.858
rhombus, spiral, spiraltemplate	75.1	83.7	81.0	0.817	0.806
signature, spiral, spiraltemplate	77.8	86.6	80.9	0.829	0.844

Table B.1: Results PD classification with spectral features

Appendix C

Chapter 4

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, circle	63.5	67.1	84.7	0.744	0.473
alphabet, circletemplate	65.5	73.7	82.1	0.766	0.530
alphabet, cube	62.3	72.9	74.3	0.727	0.572
alphabet, freewriting	64.2	71.3	83.7	0.762	0.469
alphabet, house	67.5	74.8	81.4	0.775	0.621
alphabet, id	64.6	69.4	86.8	0.766	0.535
alphabet, line1	64.2	70.4	83.0	0.754	0.534
alphabet, line2	72.9	78.2	88.5	0.826	0.592
alphabet, name	67.1	72.0	86.0	0.778	0.544
alphabet, numbers	67.3	72.2	86.6	0.783	0.562
alphabet, rectangles	61.0	71.1	74.9	0.723	0.520
alphabet, rey	64.9	69.2	87.6	0.767	0.570
alphabet, rhombus	71.7	77.6	85.1	0.807	0.707
alphabet, signature	69.0	75.8	81.6	0.782	0.669
alphabet, spiral	73.4	80.7	81.9	0.810	0.702
alphabet, spiraltemplate	67.4	72.5	86.6	0.781	0.570
circle, circletemplate	69.2	73.0	92.0	0.808	0.434
circle, cube	69.4	77.6	80.1	0.783	0.629
circle, freewriting	61.1	68.9	79.9	0.731	0.483
circle, house	70.4	79.2	80.0	0.792	0.617
circle, id	63.3	69.1	87.4	0.766	0.435
circle, line1	67.0	72.7	88.2	0.789	0.510
circle, line2	63.2	67.8	81.1	0.733	0.443
circle, name	62.0	70.0	79.9	0.738	0.553
circle, numbers	66.2	72.4	85.8	0.779	0.533

Continued on next page

Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circle, rectangles	61.9	70.5	74.7	0.719	0.560
circle, rey	68.8	74.7	84.7	0.789	0.599
circle, rhombus	73.5	78.5	86.4	0.819	0.738
circle, signature	62.3	70.6	74.6	0.718	0.532
circle, spiral	77.2	80.9	88.5	0.841	0.702
circle, spiraltemplate	65.2	76.3	75.9	0.756	0.591
circletemplate, cube	71.5	78.4	83.2	0.803	0.650
circletemplate, freewriting	61.6	69.2	80.9	0.734	0.436
circletemplate, house	72.8	80.5	83.9	0.817	0.624
circletemplate, id	65.2	69.7	87.0	0.767	0.441
circletemplate, line1	70.6	78.2	82.2	0.794	0.606
circletemplate, line2	58.7	69.3	73.4	0.698	0.492
circletemplate, name	71.9	77.2	89.2	0.822	0.594
circletemplate, numbers	70.2	76.0	86.1	0.800	0.567
circletemplate, rectangles	71.2	81.9	78.2	0.793	0.662
circletemplate, rey	67.1	76.2	78.5	0.767	0.641
circletemplate, rhombus	72.0	77.8	86.8	0.815	0.638
circletemplate, signature	72.6	79.5	84.2	0.813	0.675
circletemplate, spiral	75.7	81.9	86.6	0.836	0.693
circletemplate, spiraltemplate	73.5	82.0	83.4	0.821	0.670
cube, freewriting	64.2	75.8	75.0	0.749	0.544
cube, house	88.8	92.4	92.3	0.921	0.920
cube, id	68.0	76.0	80.4	0.775	0.652
cube, line1	74.0	80.5	86.6	0.829	0.665
cube, line2	65.0	76.4	77.1	0.762	0.552
cube, name	70.1	78.5	81.6	0.795	0.650
cube, numbers	73.7	80.0	85.0	0.818	0.702
cube, rectangles	80.0	84.0	88.4	0.858	0.761
cube, rey	76.7	81.5	87.8	0.843	0.747
cube, rhombus	82.9	85.8	91.5	0.883	0.819
cube, signature	79.5	87.4	83.6	0.852	0.799
cube, spiral	84.6	89.8	89.0	0.891	0.815
cube, spiraltemplate	84.8	89.6	89.8	0.894	0.833
freewriting, house	64.6	74.3	76.3	0.747	0.602
freewriting, id	63.6	70.5	82.7	0.754	0.590
freewriting, line1	66.2	74.5	84.2	0.783	0.436
freewriting, line2	54.9	65.8	65.7	0.642	0.419
freewriting, name	57.5	69.0	72.1	0.693	0.431

Continued on next page

Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
freewriting, numbers	63.8	70.8	81.3	0.751	0.524
freewriting, rectangles	57.2	67.7	69.9	0.680	0.464
freewriting, rey	63.2	72.6	78.9	0.749	0.516
freewriting, rhombus	71.0	76.7	85.2	0.804	0.700
freewriting, signature	65.4	76.8	76.3	0.759	0.639
freewriting, spiral	72.7	79.5	83.4	0.808	0.663
freewriting, spiraltemplate	65.2	74.8	76.7	0.753	0.551
house, id	71.5	76.4	85.9	0.805	0.697
house, line1	70.0	76.5	87.5	0.811	0.551
house, line2	65.7	75.4	79.1	0.765	0.513
house, name	66.7	73.6	81.4	0.768	0.623
house, numbers	70.3	78.1	81.7	0.793	0.641
house, rectangles	76.4	83.3	84.2	0.833	0.728
house, rey	75.2	81.6	84.0	0.823	0.788
house, rhombus	84.7	87.3	92.0	0.893	0.838
house, signature	81.0	87.1	86.3	0.863	0.812
house, spiral	83.0	88.7	87.6	0.879	0.807
house, spiraltemplate	84.5	88.2	90.4	0.890	0.831
id, line1	70.6	74.7	90.4	0.813	0.532
id, line2	70.5	74.4	88.5	0.804	0.490
id, name	67.0	74.6	83.2	0.781	0.603
id, numbers	67.5	72.8	86.3	0.785	0.648
id, rectangles	65.6	72.7	80.7	0.759	0.541
id, rey	65.0	70.7	83.8	0.754	0.523
id, rhombus	66.7	74.9	81.3	0.763	0.593
id, signature	67.6	73.5	84.7	0.781	0.591
id, spiral	70.7	76.9	84.5	0.800	0.628
id, spiraltemplate	68.1	72.7	86.0	0.783	0.572
line1, line2	66.2	71.3	88.5	0.780	0.535
line1, name	65.8	76.0	79.6	0.770	0.564
line1, numbers	67.5	73.6	87.2	0.790	0.554
line1, rectangles	68.4	77.7	82.2	0.792	0.571
line1, rey	66.9	75.6	79.5	0.768	0.639
line1, rhombus	71.8	78.8	85.6	0.815	0.651
line1, signature	66.1	74.3	84.3	0.779	0.550
line1, spiral	74.0	80.6	86.7	0.833	0.647
line1, spiraltemplate	68.1	77.3	82.0	0.787	0.617
line2, name	67.6	75.5	84.2	0.790	0.527

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
line2, numbers	68.9	73.5	90.5	0.804	0.465
line2, rectangles	64.8	74.5	77.1	0.752	0.527
line2, rey	64.2	73.6	80.5	0.761	0.529
line2, rhombus	72.2	77.0	86.9	0.811	0.647
line2, signature	62.9	75.3	74.0	0.738	0.450
line2, spiral	67.2	77.3	78.2	0.773	0.567
line2, spiraltemplate	60.1	74.6	71.2	0.721	0.468
name, numbers	70.2	75.6	87.2	0.804	0.616
name, rectangles	55.3	68.9	68.3	0.679	0.452
name, rey	69.4	73.5	87.7	0.796	0.658
name, rhombus	70.9	76.5	86.8	0.807	0.684
name, signature	65.8	75.2	77.8	0.759	0.612
name, spiral	73.8	79.5	84.2	0.813	0.696
name, spiraltemplate	66.6	75.8	80.0	0.772	0.550
numbers, rectangles	74.6	79.8	86.3	0.826	0.683
numbers, rey	74.3	76.5	91.5	0.829	0.710
numbers, rhombus	76.3	78.5	91.9	0.843	0.745
numbers, signature	72.9	80.4	81.8	0.805	0.718
numbers, spiral	80.7	84.3	90.0	0.868	0.716
numbers, spiraltemplate	69.1	77.5	78.6	0.775	0.636
rectangles, rey	72.1	79.1	83.8	0.808	0.681
rectangles, rhombus	83.5	86.7	91.1	0.886	0.808
rectangles, signature	74.6	81.9	81.9	0.815	0.737
rectangles, spiral	79.8	84.8	86.7	0.855	0.728
rectangles, spiraltemplate	76.6	81.0	86.6	0.833	0.691
rey, rhombus	66.9	76.3	78.9	0.753	0.683
rey, signature	71.9	79.0	84.1	0.808	0.680
rey, spiral	79.2	84.7	86.9	0.854	0.731
rey, spiraltemplate	61.9	70.6	75.1	0.721	0.564
rhombus, signature	81.2	85.1	88.7	0.865	0.808
rhombus, spiral	82.3	86.2	89.6	0.876	0.791
rhombus, spiraltemplate	84.1	85.4	93.2	0.888	0.806
signature, spiral	79.7	84.7	86.7	0.854	0.781
signature, spiraltemplate	78.7	84.2	85.2	0.844	0.772
spiral, spiraltemplate	80.5	86.4	86.9	0.863	0.756
alphabet, circle, circletemplate	67.2	68.5	94.4	0.785	0.384
alphabet, circle, cube	67.3	72.0	90.2	0.795	0.432
alphabet, circle, freewriting	65.7	66.8	94.0	0.776	0.456

Continued on next page

Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, circle, house	68.6	70.7	95.1	0.808	0.472
alphabet, circle, id	67.7	69.5	95.5	0.800	0.448
alphabet, circle, line1	71.0	73.6	95.2	0.827	0.497
alphabet, circle, line2	69.3	70.6	94.3	0.804	0.436
alphabet, circle, name	68.4	71.1	90.0	0.789	0.478
alphabet, circle, numbers	70.4	71.9	96.5	0.821	0.365
alphabet, circle, rectangles	66.2	68.2	92.9	0.783	0.434
alphabet, circle, rey	70.3	71.0	98.0	0.821	0.504
alphabet, circle, rhombus	65.3	70.0	89.4	0.779	0.471
alphabet, circle, signature	67.5	70.5	90.6	0.788	0.491
alphabet, circle, spiral	66.1	70.5	90.2	0.785	0.506
alphabet, circle, spiraltemplate	68.4	69.9	96.7	0.808	0.434
alphabet, circletemplate, cube	67.6	73.4	87.2	0.791	0.429
alphabet, circletemplate, freewriting	70.9	73.5	94.5	0.823	0.449
alphabet, circletemplate, house	65.5	68.7	91.1	0.778	0.462
alphabet, circletemplate, id	71.2	72.0	94.8	0.814	0.415
alphabet, circletemplate, line1	70.0	72.1	95.4	0.816	0.489
alphabet, circletemplate, line2	67.8	69.7	95.5	0.799	0.402
alphabet, circletemplate, name	65.3	69.7	89.9	0.777	0.477
alphabet, circletemplate, numbers	66.0	70.9	90.3	0.787	0.395
alphabet, circletemplate, rectangles	65.2	71.4	87.1	0.776	0.422
alphabet, circletemplate, rey	66.9	73.4	85.9	0.781	0.500
alphabet, circletemplate, rhombus	65.4	69.4	88.1	0.768	0.438
alphabet, circletemplate, signature	66.8	71.9	89.7	0.791	0.528
alphabet, circletemplate, spiral	71.8	73.6	95.5	0.828	0.454
alphabet, circletemplate, spiraltemplate	69.6	72.9	93.4	0.812	0.461
alphabet, cube, freewriting	65.5	69.8	90.3	0.780	0.434
alphabet, cube, house	62.9	70.1	83.5	0.751	0.534
alphabet, cube, id	64.0	69.8	85.8	0.763	0.516
alphabet, cube, line1	68.2	72.8	89.4	0.798	0.514
alphabet, cube, line2	71.5	75.4	92.3	0.826	0.494
alphabet, cube, name	62.5	67.4	83.5	0.740	0.491
alphabet, cube, numbers	69.0	70.3	95.1	0.805	0.499
alphabet, cube, rectangles	60.9	66.9	84.3	0.738	0.448
alphabet, cube, rey	66.1	68.4	91.7	0.774	0.466
alphabet, cube, rhombus	63.5	71.0	81.8	0.755	0.546
alphabet, cube, signature	64.4	70.2	85.2	0.761	0.510
alphabet, cube, spiral	62.4	68.2	85.8	0.751	0.554

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, cube, spiraltemplate	63.0	69.8	83.7	0.753	0.485
alphabet, freewriting, house	68.1	71.9	92.1	0.800	0.504
alphabet, freewriting, id	68.3	70.0	95.0	0.799	0.590
alphabet, freewriting, line1	72.3	74.5	95.4	0.832	0.489
alphabet, freewriting, line2	69.0	74.6	88.6	0.804	0.519
alphabet, freewriting, name	66.4	68.8	93.7	0.785	0.451
alphabet, freewriting, numbers	70.1	70.2	99.0	0.819	0.465
alphabet, freewriting, rectangles	64.8	67.7	88.9	0.764	0.463
alphabet, freewriting, rey	67.5	69.7	91.6	0.787	0.510
alphabet, freewriting, rhombus	65.2	69.4	89.9	0.775	0.536
alphabet, freewriting, signature	66.5	69.4	90.3	0.776	0.482
alphabet, freewriting, spiral	69.0	72.3	92.5	0.806	0.512
alphabet, freewriting, spiraltemplate	69.1	71.1	95.7	0.810	0.508
alphabet, house, id	66.6	70.9	90.0	0.786	0.533
alphabet, house, line1	72.2	73.8	97.3	0.836	0.495
alphabet, house, line2	71.0	73.6	95.1	0.824	0.441
alphabet, house, name	65.8	68.5	92.8	0.783	0.518
alphabet, house, numbers	67.5	70.1	94.1	0.798	0.472
alphabet, house, rectangles	66.6	72.0	87.7	0.782	0.546
alphabet, house, rey	64.9	68.8	87.8	0.763	0.556
alphabet, house, rhombus	69.2	73.2	88.7	0.797	0.605
alphabet, house, signature	63.5	68.0	88.4	0.758	0.557
alphabet, house, spiral	67.0	70.6	90.0	0.785	0.561
alphabet, house, spiraltemplate	64.3	69.7	88.9	0.774	0.464
alphabet, id, line1	70.5	73.8	93.6	0.819	0.522
alphabet, id, line2	72.2	75.2	93.7	0.830	0.480
alphabet, id, name	65.9	72.0	84.2	0.769	0.524
alphabet, id, numbers	64.8	69.3	89.1	0.773	0.510
alphabet, id, rectangles	69.2	71.1	94.8	0.809	0.521
alphabet, id, rey	67.0	71.2	91.1	0.785	0.534
alphabet, id, rhombus	66.2	70.9	88.4	0.782	0.489
alphabet, id, signature	66.4	71.6	88.8	0.788	0.488
alphabet, id, spiral	66.9	70.5	91.1	0.788	0.519
alphabet, id, spiraltemplate	66.8	70.4	92.4	0.794	0.511
alphabet, line1, line2	67.3	71.4	92.5	0.800	0.496
alphabet, line1, name	69.1	71.6	93.8	0.807	0.508
alphabet, line1, numbers	72.4	73.7	96.5	0.833	0.449
alphabet, line1, rectangles	71.0	74.1	93.1	0.822	0.494

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, line1, rey	67.7	73.0	89.0	0.797	0.568
alphabet, line1, rhombus	73.7	74.5	97.8	0.843	0.565
alphabet, line1, signature	72.7	74.5	95.0	0.832	0.536
alphabet, line1, spiral	71.3	72.9	95.0	0.818	0.543
alphabet, line1, spiraltemplate	67.3	71.7	91.3	0.796	0.455
alphabet, line2, name	65.5	69.9	90.9	0.784	0.472
alphabet, line2, numbers	70.1	72.0	94.7	0.813	0.470
alphabet, line2, rectangles	72.3	75.1	94.7	0.833	0.454
alphabet, line2, rey	68.1	72.7	91.0	0.802	0.479
alphabet, line2, rhombus	71.8	74.5	93.2	0.824	0.571
alphabet, line2, signature	68.5	74.3	87.3	0.796	0.538
alphabet, line2, spiral	71.5	73.9	95.2	0.826	0.476
alphabet, line2, spiraltemplate	68.3	72.7	91.2	0.800	0.420
alphabet, name, numbers	67.9	69.5	92.0	0.789	0.417
alphabet, name, rectangles	64.5	67.3	90.4	0.767	0.445
alphabet, name, rey	64.2	69.5	88.3	0.770	0.527
alphabet, name, rhombus	64.9	68.9	90.1	0.775	0.525
alphabet, name, signature	62.2	68.4	83.6	0.746	0.541
alphabet, name, spiral	65.5	70.1	88.5	0.777	0.528
alphabet, name, spiraltemplate	67.8	69.4	95.7	0.800	0.498
alphabet, numbers, rectangles	66.1	69.1	91.7	0.784	0.456
alphabet, numbers, rey	66.4	67.5	91.3	0.762	0.430
alphabet, numbers, rhombus	65.0	68.8	92.0	0.780	0.425
alphabet, numbers, signature	65.3	68.9	90.3	0.775	0.518
alphabet, numbers, spiral	66.1	70.8	88.2	0.779	0.520
alphabet, numbers, spiraltemplate	66.1	69.8	89.7	0.779	0.461
alphabet, rectangles, rey	62.3	67.5	88.0	0.759	0.445
alphabet, rectangles, rhombus	64.2	71.8	83.2	0.761	0.524
alphabet, rectangles, signature	64.6	70.4	85.2	0.764	0.539
alphabet, rectangles, spiral	62.5	70.4	81.2	0.746	0.535
alphabet, rectangles, spiraltemplate	64.6	68.4	90.6	0.773	0.485
alphabet, rey, rhombus	63.4	68.6	84.4	0.735	0.523
alphabet, rey, signature	66.6	71.0	89.8	0.786	0.551
alphabet, rey, spiral	68.9	70.5	96.1	0.809	0.484
alphabet, rey, spiraltemplate	65.8	69.8	89.7	0.779	0.481
alphabet, rhombus, signature	66.9	71.5	89.3	0.784	0.608
alphabet, rhombus, spiral	69.6	74.7	86.9	0.798	0.619
alphabet, rhombus, spiraltemplate	65.7	71.2	87.4	0.779	0.540

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
alphabet, signature, spiral	63.6	69.3	85.9	0.759	0.584
alphabet, signature, spiraltemplate	65.8	68.2	89.3	0.767	0.521
alphabet, spiral, spiraltemplate	62.0	68.5	84.1	0.746	0.544
circle, circletemplate, cube	68.5	71.6	90.7	0.793	0.379
circle, circletemplate, freewriting	69.5	68.9	95.0	0.793	0.329
circle, circletemplate, house	68.3	71.0	90.5	0.789	0.452
circle, circletemplate, id	68.5	70.2	96.7	0.807	0.381
circle, circletemplate, line1	67.0	72.1	90.5	0.797	0.383
circle, circletemplate, line2	69.2	68.2	95.6	0.792	0.345
circle, circletemplate, name	64.4	68.4	85.2	0.743	0.435
circle, circletemplate, numbers	66.2	67.6	91.6	0.773	0.387
circle, circletemplate, rectangles	65.6	70.9	86.3	0.770	0.411
circle, circletemplate, rey	66.9	69.8	92.8	0.788	0.412
circle, circletemplate, rhombus	68.5	73.3	90.6	0.802	0.444
circle, circletemplate, signature	67.1	70.3	92.1	0.792	0.456
circle, circletemplate, spiral	68.6	70.7	92.9	0.799	0.443
circle, circletemplate, spiraltemplate	67.3	73.8	88.0	0.792	0.390
circle, cube, freewriting	62.9	69.2	86.4	0.763	0.413
circle, cube, house	64.4	71.2	83.9	0.763	0.542
circle, cube, id	63.8	63.6	84.9	0.724	0.423
circle, cube, line1	67.1	71.0	89.3	0.784	0.533
circle, cube, line2	66.1	71.6	86.5	0.775	0.425
circle, cube, name	61.5	71.9	77.3	0.734	0.496
circle, cube, numbers	65.8	70.6	85.7	0.768	0.485
circle, cube, rectangles	66.4	72.2	85.7	0.776	0.549
circle, cube, rey	67.5	72.2	88.9	0.792	0.524
circle, cube, rhombus	66.9	72.8	85.9	0.782	0.576
circle, cube, signature	67.0	73.1	84.4	0.777	0.501
circle, cube, spiral	66.8	74.2	82.9	0.777	0.563
circle, cube, spiraltemplate	59.8	69.0	77.1	0.721	0.485
circle, freewriting, house	65.2	68.8	88.0	0.768	0.417
circle, freewriting, id	69.6	71.1	96.5	0.815	0.508
circle, freewriting, line1	71.5	73.8	95.2	0.827	0.406
circle, freewriting, line2	67.3	71.7	91.2	0.798	0.428
circle, freewriting, name	66.2	67.7	93.2	0.780	0.431
circle, freewriting, numbers	71.9	72.8	97.0	0.829	0.495
circle, freewriting, rectangles	65.9	68.6	90.4	0.775	0.480
circle, freewriting, rey	66.5	66.8	93.4	0.775	0.498

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circle, freewriting, rhombus	69.0	71.2	95.1	0.811	0.517
circle, freewriting, signature	65.1	69.4	89.1	0.775	0.491
circle, freewriting, spiral	67.8	72.3	90.2	0.797	0.522
circle, freewriting, spiraltemplate	67.1	70.8	92.4	0.797	0.371
circle, house, id	69.2	71.3	95.2	0.810	0.507
circle, house, line1	71.3	72.9	95.9	0.825	0.486
circle, house, line2	69.4	74.1	86.7	0.794	0.472
circle, house, name	62.6	68.5	83.4	0.744	0.556
circle, house, numbers	68.9	72.6	91.9	0.807	0.531
circle, house, rectangles	60.6	66.9	81.7	0.731	0.440
circle, house, rey	68.2	69.3	89.9	0.778	0.517
circle, house, rhombus	66.7	71.8	88.7	0.784	0.560
circle, house, signature	61.9	70.0	79.1	0.733	0.469
circle, house, spiral	68.0	74.0	84.8	0.785	0.577
circle, house, spiraltemplate	59.0	68.6	77.8	0.717	0.472
circle, id, line1	71.2	73.1	96.4	0.828	0.524
circle, id, line2	67.7	68.8	90.1	0.775	0.436
circle, id, name	64.1	68.4	88.8	0.768	0.474
circle, id, numbers	68.7	69.9	97.4	0.811	0.395
circle, id, rectangles	63.6	65.1	88.2	0.746	0.373
circle, id, rey	63.6	58.7	82.6	0.683	0.401
circle, id, rhombus	66.2	66.1	90.0	0.759	0.443
circle, id, signature	67.4	69.2	96.0	0.799	0.446
circle, id, spiral	67.8	68.6	95.0	0.792	0.476
circle, id, spiraltemplate	70.5	71.2	98.7	0.825	0.449
circle, line1, line2	70.6	73.1	95.6	0.822	0.476
circle, line1, name	70.7	74.8	91.8	0.818	0.527
circle, line1, numbers	71.9	73.6	93.1	0.819	0.464
circle, line1, rectangles	66.7	73.6	87.2	0.788	0.479
circle, line1, rey	69.6	74.2	91.2	0.813	0.504
circle, line1, rhombus	67.8	72.8	90.1	0.796	0.472
circle, line1, signature	72.5	74.2	96.2	0.834	0.529
circle, line1, spiral	70.9	73.5	94.6	0.822	0.514
circle, line1, spiraltemplate	66.9	73.6	87.5	0.792	0.452
circle, line2, name	73.4	75.2	96.5	0.842	0.456
circle, line2, numbers	67.3	69.7	91.2	0.786	0.332
circle, line2, rectangles	70.9	73.6	94.1	0.820	0.469
circle, line2, rey	70.2	71.2	94.7	0.810	0.433

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circle, line2, rhombus	70.3	72.8	94.5	0.819	0.423
circle, line2, signature	67.0	72.9	85.5	0.782	0.444
circle, line2, spiral	71.2	75.4	91.8	0.822	0.464
circle, line2, spiraltemplate	65.5	70.3	88.4	0.777	0.436
circle, name, numbers	69.6	71.7	95.4	0.815	0.416
circle, name, rectangles	63.4	69.3	86.5	0.763	0.459
circle, name, rey	64.9	70.5	87.2	0.773	0.480
circle, name, rhombus	63.1	69.4	86.3	0.758	0.537
circle, name, signature	64.3	70.9	86.8	0.772	0.474
circle, name, spiral	65.2	72.2	85.0	0.775	0.525
circle, name, spiraltemplate	66.2	70.0	90.2	0.783	0.503
circle, numbers, rectangles	65.0	67.3	91.6	0.772	0.438
circle, numbers, rey	67.2	69.1	91.4	0.780	0.417
circle, numbers, rhombus	66.2	69.7	91.9	0.788	0.423
circle, numbers, signature	67.6	70.0	94.1	0.797	0.391
circle, numbers, spiral	67.1	71.9	89.4	0.789	0.512
circle, numbers, spiraltemplate	67.0	68.6	92.5	0.783	0.364
circle, rectangles, rey	67.3	70.4	91.8	0.793	0.469
circle, rectangles, rhombus	63.0	68.9	85.0	0.755	0.484
circle, rectangles, signature	61.7	67.8	78.0	0.719	0.465
circle, rectangles, spiral	67.0	73.9	84.4	0.782	0.546
circle, rectangles, spiraltemplate	63.6	69.4	83.8	0.752	0.450
circle, rey, rhombus	68.8	71.2	92.7	0.801	0.584
circle, rey, signature	66.6	68.9	89.2	0.773	0.456
circle, rey, spiral	68.1	73.3	87.1	0.789	0.547
circle, rey, spiraltemplate	64.7	68.4	91.3	0.776	0.436
circle, rhombus, signature	67.2	74.9	84.0	0.783	0.574
circle, rhombus, spiral	70.9	75.8	87.1	0.806	0.619
circle, rhombus, spiraltemplate	65.9	71.1	88.3	0.781	0.490
circle, signature, spiral	65.6	73.7	81.8	0.768	0.540
circle, signature, spiraltemplate	63.0	67.9	83.3	0.742	0.473
circle, spiral, spiraltemplate	66.1	73.3	82.7	0.771	0.528
circletemplate, cube, freewriting	66.4	70.0	89.0	0.778	0.386
circletemplate, cube, house	66.9	73.9	82.1	0.771	0.510
circletemplate, cube, id	67.7	72.2	90.8	0.798	0.401
circletemplate, cube, line1	68.6	74.0	87.3	0.795	0.544
circletemplate, cube, line2	68.0	72.0	89.4	0.791	0.396
circletemplate, cube, name	67.3	72.5	87.8	0.789	0.488

Continued on next page

Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circletemplate, cube, numbers	68.0	74.4	86.8	0.793	0.435
circletemplate, cube, rectangles	65.6	73.9	82.9	0.775	0.443
circletemplate, cube, rey	70.2	76.6	86.7	0.805	0.585
circletemplate, cube, rhombus	66.9	73.7	85.2	0.784	0.492
circletemplate, cube, signature	66.5	68.5	91.5	0.780	0.375
circletemplate, cube, spiral	65.0	69.1	86.8	0.763	0.436
circletemplate, cube, spiraltemplate	64.3	73.2	81.8	0.761	0.464
circletemplate, freewriting, house	67.3	73.3	88.9	0.796	0.393
circletemplate, freewriting, id	67.4	71.3	92.7	0.800	0.425
circletemplate, freewriting, line1	69.2	73.3	92.3	0.811	0.496
circletemplate, freewriting, line2	68.8	73.5	91.2	0.808	0.368
circletemplate, freewriting, name	70.0	75.1	90.8	0.814	0.496
circletemplate, freewriting, numbers	67.5	72.0	91.2	0.795	0.395
circletemplate, freewriting, rectangles	67.9	73.8	88.6	0.798	0.392
circletemplate, freewriting, rey	66.8	72.7	87.6	0.786	0.436
circletemplate, freewriting, rhombus	65.1	69.0	91.2	0.778	0.512
circletemplate, freewriting, signature	70.4	73.0	94.9	0.819	0.455
circletemplate, freewriting, spiral	70.2	73.3	94.5	0.819	0.395
circletemplate, freewriting, spiraltemplate	69.8	74.3	91.7	0.814	0.354
circletemplate, house, id	70.6	72.5	95.1	0.819	0.484
circletemplate, house, line1	68.9	71.5	94.4	0.806	0.419
circletemplate, house, line2	66.3	71.4	89.1	0.784	0.392
circletemplate, house, name	66.9	71.6	89.7	0.789	0.453
circletemplate, house, numbers	67.3	70.2	90.3	0.784	0.445
circletemplate, house, rectangles	63.3	71.4	80.1	0.747	0.471
circletemplate, house, rey	67.9	72.8	87.4	0.787	0.555
circletemplate, house, rhombus	63.7	71.4	82.3	0.756	0.475
circletemplate, house, signature	69.0	71.9	89.9	0.793	0.425
circletemplate, house, spiral	67.5	72.0	90.7	0.795	0.481
circletemplate, house, spiraltemplate	66.4	75.7	81.8	0.774	0.491
circletemplate, id, line1	70.3	74.5	91.8	0.818	0.504
circletemplate, id, line2	69.5	71.6	95.4	0.813	0.397
circletemplate, id, name	68.6	73.3	91.4	0.798	0.496
circletemplate, id, numbers	67.0	70.9	87.5	0.775	0.421
circletemplate, id, rectangles	66.7	70.0	91.7	0.788	0.409
circletemplate, id, rey	65.3	66.9	86.9	0.741	0.463
circletemplate, id, rhombus	68.7	72.3	92.2	0.804	0.407
circletemplate, id, signature	71.8	73.6	95.9	0.830	0.447

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circletemplate, id, spiral	69.6	71.6	93.1	0.804	0.408
circletemplate, id, spiraltemplate	68.9	73.2	90.2	0.804	0.472
circletemplate, line1, line2	67.1	68.7	94.6	0.791	0.426
circletemplate, line1, name	68.1	73.4	87.3	0.792	0.580
circletemplate, line1, numbers	68.7	74.2	87.8	0.797	0.545
circletemplate, line1, rectangles	67.6	76.0	84.6	0.790	0.511
circletemplate, line1, rey	70.9	75.3	89.5	0.809	0.632
circletemplate, line1, rhombus	67.5	73.5	87.7	0.791	0.518
circletemplate, line1, signature	68.8	74.5	88.1	0.802	0.522
circletemplate, line1, spiral	69.4	74.5	88.5	0.803	0.566
circletemplate, line1, spiraltemplate	68.2	74.6	85.1	0.788	0.457
circletemplate, line2, name	67.6	72.2	89.6	0.794	0.428
circletemplate, line2, numbers	67.4	68.6	92.3	0.781	0.347
circletemplate, line2, rectangles	63.4	70.4	86.0	0.763	0.385
circletemplate, line2, rey	66.7	70.4	91.8	0.788	0.407
circletemplate, line2, rhombus	68.7	73.3	90.9	0.805	0.480
circletemplate, line2, signature	66.2	71.0	90.4	0.785	0.395
circletemplate, line2, spiral	66.7	72.3	89.5	0.788	0.362
circletemplate, line2, spiraltemplate	63.6	68.3	87.5	0.758	0.428
circletemplate, name, numbers	67.6	72.0	88.6	0.789	0.463
circletemplate, name, rectangles	67.9	72.9	89.3	0.797	0.459
circletemplate, name, rey	66.9	71.3	89.8	0.790	0.460
circletemplate, name, rhombus	68.5	73.5	90.4	0.805	0.454
circletemplate, name, signature	67.6	73.3	86.1	0.785	0.515
circletemplate, name, spiral	69.6	72.9	92.5	0.810	0.452
circletemplate, name, spiraltemplate	67.5	73.0	85.8	0.780	0.490
circletemplate, numbers, rectangles	67.5	69.8	92.0	0.786	0.483
circletemplate, numbers, rey	68.8	72.0	89.0	0.790	0.556
circletemplate, numbers, rhombus	66.7	74.4	83.3	0.777	0.448
circletemplate, numbers, signature	67.2	70.3	87.6	0.772	0.478
circletemplate, numbers, spiral	69.2	72.8	90.8	0.802	0.479
circletemplate, numbers, spiraltemplate	67.6	74.2	87.6	0.792	0.401
circletemplate, rectangles, rey	64.3	73.2	79.1	0.751	0.536
circletemplate, rectangles, rhombus	67.6	75.6	81.4	0.780	0.553
circletemplate, rectangles, signature	66.8	75.7	83.2	0.785	0.531
circletemplate, rectangles, spiral	68.9	73.1	91.1	0.801	0.489
circletemplate, rectangles, spiraltemplate	61.0	69.1	81.7	0.735	0.400
circletemplate, rey, rhombus	69.5	73.4	90.4	0.804	0.602

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
circletemplate, rey, signature	68.6	75.5	85.8	0.796	0.541
circletemplate, rey, spiral	63.4	71.5	83.5	0.760	0.452
circletemplate, rey, spiraltemplate	63.9	73.5	80.3	0.759	0.528
circletemplate, rhombus, signature	66.2	73.6	85.6	0.783	0.429
circletemplate, rhombus, spiral	68.0	72.6	88.0	0.790	0.517
circletemplate, rhombus, spiraltemplate	65.7	72.7	82.7	0.766	0.463
circletemplate, signature, spiral	69.2	73.0	91.5	0.808	0.506
circletemplate, signature, spiraltemplate	67.6	74.7	86.1	0.789	0.472
circletemplate, spiral, spiraltemplate	63.9	72.5	82.3	0.761	0.436
cube, freewriting, house	62.5	70.8	77.5	0.734	0.559
cube, freewriting, id	69.2	71.3	95.1	0.811	0.448
cube, freewriting, line1	66.9	71.7	88.8	0.789	0.490
cube, freewriting, line2	60.8	70.2	77.6	0.729	0.371
cube, freewriting, name	59.5	68.4	76.9	0.716	0.424
cube, freewriting, numbers	66.3	66.6	90.5	0.764	0.417
cube, freewriting, rectangles	55.2	66.0	69.0	0.666	0.418
cube, freewriting, rey	68.0	72.0	91.1	0.800	0.496
cube, freewriting, rhombus	63.8	70.4	82.8	0.753	0.505
cube, freewriting, signature	60.8	70.2	74.1	0.714	0.560
cube, freewriting, spiral	64.5	73.0	76.7	0.741	0.518
cube, freewriting, spiraltemplate	56.9	68.0	73.1	0.696	0.427
cube, house, id	68.2	74.3	85.4	0.790	0.624
cube, house, line1	68.8	74.3	88.1	0.798	0.540
cube, house, line2	66.1	74.4	82.4	0.777	0.512
cube, house, name	67.3	73.7	82.4	0.772	0.633
cube, house, numbers	66.6	72.2	86.4	0.781	0.541
cube, house, rectangles	67.7	75.5	79.1	0.769	0.647
cube, house, rey	68.9	74.5	83.6	0.783	0.666
cube, house, rhombus	74.0	79.5	86.2	0.823	0.721
cube, house, signature	70.9	78.4	79.7	0.786	0.689
cube, house, spiral	71.6	79.0	82.2	0.800	0.652
cube, house, spiraltemplate	70.0	77.9	80.3	0.787	0.647
cube, id, line1	71.1	75.3	91.8	0.823	0.535
cube, id, line2	74.1	74.6	99.0	0.848	0.420
cube, id, name	66.7	72.1	86.8	0.783	0.521
cube, id, numbers	69.1	72.9	89.9	0.801	0.562
cube, id, rectangles	60.9	68.1	83.0	0.738	0.481
cube, id, rey	64.6	70.9	85.3	0.769	0.513

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
cube, id, rhombus	68.3	73.9	86.5	0.791	0.620
cube, id, signature	64.8	72.0	83.3	0.768	0.499
cube, id, spiral	68.3	73.2	86.1	0.787	0.576
cube, id, spiraltemplate	63.4	71.7	82.2	0.758	0.487
cube, line1, line2	69.6	73.4	92.4	0.813	0.490
cube, line1, name	68.7	76.0	87.1	0.801	0.558
cube, line1, numbers	70.4	75.7	88.4	0.808	0.584
cube, line1, rectangles	73.1	75.6	94.7	0.837	0.497
cube, line1, rey	70.2	73.4	92.1	0.811	0.583
cube, line1, rhombus	68.4	74.9	86.9	0.798	0.556
cube, line1, signature	71.0	75.2	91.6	0.821	0.506
cube, line1, spiral	70.5	73.8	93.3	0.819	0.568
cube, line1, spiraltemplate	69.1	74.9	87.3	0.799	0.584
cube, line2, name	66.5	72.7	86.5	0.781	0.487
cube, line2, numbers	73.3	74.1	98.4	0.843	0.372
cube, line2, rectangles	61.1	69.4	77.9	0.725	0.403
cube, line2, rey	68.3	72.1	92.0	0.803	0.500
cube, line2, rhombus	67.6	72.2	85.0	0.774	0.468
cube, line2, signature	59.2	67.4	74.6	0.698	0.430
cube, line2, spiral	65.3	75.1	80.8	0.771	0.433
cube, line2, spiraltemplate	62.3	74.0	75.4	0.740	0.487
cube, name, numbers	62.3	69.6	84.4	0.750	0.498
cube, name, rectangles	65.1	72.7	83.3	0.770	0.514
cube, name, rey	66.6	72.6	84.7	0.775	0.597
cube, name, rhombus	63.3	70.2	82.4	0.752	0.538
cube, name, signature	63.5	72.8	78.7	0.748	0.543
cube, name, spiral	67.3	72.6	86.0	0.782	0.611
cube, name, spiraltemplate	62.6	70.0	81.7	0.747	0.499
cube, numbers, rectangles	66.1	71.5	87.5	0.780	0.523
cube, numbers, rey	67.4	72.2	87.6	0.784	0.596
cube, numbers, rhombus	70.0	75.5	85.7	0.798	0.609
cube, numbers, signature	64.0	71.4	80.8	0.752	0.534
cube, numbers, spiral	72.1	78.0	85.5	0.811	0.671
cube, numbers, spiraltemplate	61.8	70.0	80.6	0.741	0.447
cube, rectangles, rey	66.8	74.3	82.7	0.776	0.619
cube, rectangles, rhombus	71.7	78.0	84.2	0.807	0.655
cube, rectangles, signature	65.5	76.1	76.7	0.757	0.601
cube, rectangles, spiral	74.5	80.4	85.8	0.826	0.651

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
cube, rectangles, spiraltemplate	64.8	73.5	77.5	0.749	0.545
cube, rey, rhombus	69.1	74.7	85.7	0.794	0.650
cube, rey, signature	65.2	69.0	86.2	0.760	0.527
cube, rey, spiral	73.7	76.6	89.9	0.822	0.713
cube, rey, spiraltemplate	64.2	71.8	82.9	0.763	0.493
cube, rhombus, signature	69.6	75.6	85.5	0.797	0.660
cube, rhombus, spiral	74.3	78.3	86.6	0.819	0.691
cube, rhombus, spiraltemplate	67.4	73.4	84.9	0.781	0.594
cube, signature, spiral	70.9	77.2	82.5	0.793	0.666
cube, signature, spiraltemplate	67.5	77.2	76.9	0.763	0.634
cube, spiral, spiraltemplate	70.6	77.8	80.5	0.786	0.652
freewriting, house, id	70.8	73.8	93.2	0.819	0.595
freewriting, house, line1	72.3	74.1	96.3	0.835	0.427
freewriting, house, line2	63.5	71.7	79.1	0.746	0.393
freewriting, house, name	66.1	72.1	87.2	0.783	0.479
freewriting, house, numbers	68.2	71.1	91.6	0.797	0.532
freewriting, house, rectangles	60.6	71.1	76.9	0.729	0.455
freewriting, house, rey	65.9	70.6	90.3	0.783	0.537
freewriting, house, rhombus	65.5	71.3	86.3	0.774	0.534
freewriting, house, signature	59.3	70.3	73.0	0.708	0.478
freewriting, house, spiral	66.3	74.9	81.3	0.774	0.504
freewriting, house, spiraltemplate	59.2	69.8	74.7	0.716	0.468
freewriting, id, line1	73.5	75.0	97.3	0.843	0.545
freewriting, id, line2	73.2	74.6	97.2	0.841	0.480
freewriting, id, name	66.1	68.7	94.4	0.790	0.488
freewriting, id, numbers	69.1	72.4	92.7	0.808	0.528
freewriting, id, rectangles	67.3	69.8	94.1	0.798	0.464
freewriting, id, rey	64.9	70.1	85.9	0.766	0.475
freewriting, id, rhombus	64.4	70.9	86.1	0.770	0.515
freewriting, id, signature	66.1	70.0	91.4	0.786	0.491
freewriting, id, spiral	66.7	68.9	94.0	0.792	0.522
freewriting, id, spiraltemplate	65.6	67.8	91.6	0.774	0.505
freewriting, line1, line2	73.0	74.3	95.3	0.830	0.355
freewriting, line1, name	66.9	71.4	88.4	0.785	0.371
freewriting, line1, numbers	71.6	73.9	92.9	0.820	0.448
freewriting, line1, rectangles	68.6	74.4	88.7	0.804	0.393
freewriting, line1, rey	67.6	73.6	89.3	0.799	0.473
freewriting, line1, rhombus	73.1	73.9	97.7	0.839	0.411

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
freewriting, line1, signature	75.0	76.7	97.0	0.853	0.351
freewriting, line1, spiral	72.1	74.0	93.3	0.822	0.491
freewriting, line1, spiraltemplate	71.7	75.8	92.1	0.829	0.442
freewriting, line2, name	68.6	72.0	89.6	0.792	0.481
freewriting, line2, numbers	73.0	74.4	95.6	0.833	0.461
freewriting, line2, rectangles	63.0	71.9	82.3	0.757	0.452
freewriting, line2, rey	69.8	73.5	92.1	0.812	0.486
freewriting, line2, rhombus	68.8	73.6	89.4	0.803	0.495
freewriting, line2, signature	65.6	71.1	80.8	0.751	0.425
freewriting, line2, spiral	66.1	72.6	84.0	0.771	0.394
freewriting, line2, spiraltemplate	55.9	67.7	69.6	0.681	0.298
freewriting, name, numbers	67.3	70.8	92.4	0.797	0.445
freewriting, name, rectangles	63.2	69.9	85.5	0.762	0.359
freewriting, name, rey	66.2	70.5	89.6	0.784	0.497
freewriting, name, rhombus	69.7	70.7	96.4	0.813	0.475
freewriting, name, signature	63.7	71.8	82.9	0.761	0.441
freewriting, name, spiral	63.2	70.8	82.4	0.754	0.478
freewriting, name, spiraltemplate	64.7	65.9	86.6	0.744	0.358
freewriting, numbers, rectangles	67.8	69.3	93.0	0.791	0.563
freewriting, numbers, rey	67.6	71.4	91.9	0.799	0.453
freewriting, numbers, rhombus	66.8	69.9	93.1	0.793	0.539
freewriting, numbers, signature	67.0	71.4	89.9	0.791	0.516
freewriting, numbers, spiral	69.1	72.0	92.8	0.809	0.487
freewriting, numbers, spiraltemplate	63.9	68.0	86.7	0.757	0.413
freewriting, rectangles, rey	69.6	71.8	94.3	0.812	0.495
freewriting, rectangles, rhombus	65.7	70.2	89.4	0.782	0.498
freewriting, rectangles, signature	60.0	68.7	76.4	0.717	0.487
freewriting, rectangles, spiral	66.7	72.1	86.2	0.779	0.502
freewriting, rectangles, spiraltemplate	53.5	64.1	69.8	0.660	0.367
freewriting, rey, rhombus	65.7	69.5	90.3	0.773	0.542
freewriting, rey, signature	66.6	70.4	90.9	0.788	0.486
freewriting, rey, spiral	69.2	71.9	91.0	0.798	0.487
freewriting, rey, spiraltemplate	64.9	68.3	92.1	0.779	0.460
freewriting, rhombus, signature	66.2	70.1	89.4	0.779	0.519
freewriting, rhombus, spiral	68.7	72.0	90.9	0.799	0.564
freewriting, rhombus, spiraltemplate	66.0	70.7	88.6	0.781	0.511
freewriting, signature, spiral	60.8	70.8	76.2	0.728	0.517
freewriting, signature, spiraltemplate	56.2	64.3	73.6	0.680	0.395

Continued on next page

Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
freewriting, spiral, spiraltemplate	62.7	71.6	78.6	0.743	0.474
house, id, line1	72.4	73.7	97.6	0.836	0.552
house, id, line2	68.8	72.5	92.7	0.807	0.489
house, id, name	68.3	73.3	88.2	0.793	0.592
house, id, numbers	68.6	73.5	88.6	0.797	0.555
house, id, rectangles	65.1	70.2	88.7	0.776	0.527
house, id, rey	65.8	70.7	87.6	0.777	0.568
house, id, rhombus	70.2	74.1	87.3	0.795	0.568
house, id, signature	66.4	70.8	89.9	0.786	0.529
house, id, spiral	68.8	72.7	89.1	0.797	0.565
house, id, spiraltemplate	62.5	69.7	84.4	0.752	0.533
house, line1, line2	69.4	73.3	92.7	0.813	0.418
house, line1, name	70.9	73.1	95.5	0.824	0.515
house, line1, numbers	71.8	74.1	94.7	0.828	0.449
house, line1, rectangles	70.0	73.3	93.1	0.813	0.469
house, line1, rey	69.3	73.8	87.2	0.794	0.579
house, line1, rhombus	74.0	75.6	97.2	0.847	0.474
house, line1, signature	72.6	73.6	98.0	0.838	0.484
house, line1, spiral	75.4	76.0	98.7	0.855	0.524
house, line1, spiraltemplate	69.4	74.3	91.2	0.809	0.524
house, line2, name	68.2	71.9	88.3	0.785	0.486
house, line2, numbers	68.4	72.9	88.8	0.794	0.364
house, line2, rectangles	63.4	73.5	79.4	0.756	0.454
house, line2, rey	68.2	73.3	87.9	0.792	0.539
house, line2, rhombus	71.4	75.2	91.4	0.820	0.527
house, line2, signature	64.0	71.8	80.4	0.751	0.430
house, line2, spiral	62.9	70.9	80.8	0.744	0.428
house, line2, spiraltemplate	57.8	70.8	71.9	0.702	0.386
house, name, numbers	67.7	72.3	88.3	0.789	0.516
house, name, rectangles	66.6	71.8	86.6	0.780	0.523
house, name, rey	69.0	73.6	87.4	0.792	0.645
house, name, rhombus	69.2	73.8	87.7	0.798	0.575
house, name, signature	68.9	74.3	87.3	0.799	0.567
house, name, spiral	69.6	74.2	88.5	0.802	0.562
house, name, spiraltemplate	63.0	69.0	83.3	0.749	0.490
house, numbers, rectangles	68.2	73.0	88.5	0.795	0.537
house, numbers, rey	67.3	70.3	92.1	0.791	0.586
house, numbers, rhombus	66.6	73.0	85.0	0.779	0.530

Continued on next page

Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
house, numbers, signature	65.3	71.4	85.4	0.771	0.545
house, numbers, spiral	72.4	74.7	91.8	0.820	0.613
house, numbers, spiraltemplate	60.9	68.6	81.3	0.734	0.462
house, rectangles, rey	68.8	74.2	86.5	0.794	0.616
house, rectangles, rhombus	65.8	72.9	81.4	0.763	0.596
house, rectangles, signature	63.9	72.6	75.4	0.735	0.562
house, rectangles, spiral	68.6	74.8	83.8	0.786	0.578
house, rectangles, spiraltemplate	61.4	70.7	73.1	0.714	0.473
house, rey, rhombus	68.6	75.6	84.5	0.791	0.598
house, rey, signature	66.5	73.6	84.6	0.779	0.560
house, rey, spiral	74.0	76.7	92.2	0.832	0.648
house, rey, spiraltemplate	63.0	68.8	83.0	0.746	0.496
house, rhombus, signature	68.4	75.9	84.1	0.789	0.579
house, rhombus, spiral	74.7	77.8	90.6	0.832	0.685
house, rhombus, spiraltemplate	72.0	76.9	88.3	0.817	0.613
house, signature, spiral	65.9	74.5	78.0	0.757	0.578
house, signature, spiraltemplate	63.0	74.1	72.7	0.727	0.574
house, spiral, spiraltemplate	69.0	76.9	79.4	0.776	0.594
id, line1, line2	69.8	72.6	94.3	0.816	0.413
id, line1, name	71.0	75.7	91.4	0.823	0.510
id, line1, numbers	70.7	75.2	91.7	0.820	0.541
id, line1, rectangles	68.8	73.2	91.5	0.809	0.474
id, line1, rey	71.3	73.5	95.4	0.827	0.516
id, line1, rhombus	69.7	72.5	94.9	0.817	0.498
id, line1, signature	69.8	70.9	96.9	0.813	0.470
id, line1, spiral	71.2	73.1	96.4	0.828	0.523
id, line1, spiraltemplate	68.8	73.2	90.8	0.806	0.500
id, line2, name	68.8	72.3	93.5	0.810	0.508
id, line2, numbers	69.6	71.8	96.1	0.815	0.436
id, line2, rectangles	69.4	70.8	94.1	0.802	0.448
id, line2, rey	72.0	73.9	96.1	0.831	0.415
id, line2, rhombus	70.5	73.2	93.6	0.817	0.511
id, line2, signature	68.3	70.6	94.2	0.801	0.458
id, line2, spiral	71.4	73.3	96.1	0.829	0.476
id, line2, spiraltemplate	69.7	73.3	91.7	0.810	0.424
id, name, numbers	64.9	70.2	87.6	0.776	0.524
id, name, rectangles	58.1	65.5	79.7	0.711	0.431
id, name, rey	68.0	71.9	89.0	0.789	0.517

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
id, name, rhombus	64.5	70.4	85.3	0.764	0.499
id, name, signature	66.7	72.8	85.9	0.784	0.526
id, name, spiral	66.5	71.3	89.2	0.787	0.519
id, name, spiraltemplate	63.4	69.3	86.2	0.764	0.458
id, numbers, rectangles	66.7	72.6	86.6	0.784	0.525
id, numbers, rey	69.8	72.7	92.9	0.813	0.593
id, numbers, rhombus	65.2	70.7	85.8	0.769	0.527
id, numbers, signature	65.1	71.1	86.5	0.772	0.490
id, numbers, spiral	70.6	74.4	89.1	0.807	0.630
id, numbers, spiraltemplate	60.0	67.3	81.6	0.730	0.458
id, rectangles, rey	64.4	69.1	89.2	0.772	0.432
id, rectangles, rhombus	63.5	69.8	85.3	0.761	0.452
id, rectangles, signature	59.2	67.3	78.9	0.713	0.435
id, rectangles, spiral	63.5	69.2	85.4	0.756	0.517
id, rectangles, spiraltemplate	61.2	65.7	87.2	0.743	0.440
id, rey, rhombus	57.9	66.7	73.8	0.659	0.496
id, rey, signature	66.1	68.8	92.2	0.783	0.486
id, rey, spiral	66.5	72.3	86.8	0.782	0.553
id, rey, spiraltemplate	67.8	70.1	94.9	0.803	0.435
id, rhombus, signature	69.3	74.7	88.5	0.805	0.609
id, rhombus, spiral	69.3	73.3	89.3	0.800	0.577
id, rhombus, spiraltemplate	69.8	74.1	89.3	0.807	0.591
id, signature, spiral	66.3	71.2	87.5	0.781	0.522
id, signature, spiraltemplate	67.1	69.7	90.2	0.780	0.546
id, spiral, spiraltemplate	63.3	68.0	86.5	0.755	0.477
line1, line2, name	66.7	72.8	87.9	0.788	0.479
line1, line2, numbers	72.1	73.7	96.6	0.832	0.394
line1, line2, rectangles	67.8	73.2	90.0	0.798	0.430
line1, line2, rey	69.2	72.8	92.3	0.809	0.517
line1, line2, rhombus	69.0	73.2	91.1	0.805	0.464
line1, line2, signature	68.6	72.8	91.8	0.804	0.440
line1, line2, spiral	70.2	72.6	94.7	0.819	0.425
line1, line2, spiraltemplate	69.0	71.4	95.0	0.809	0.440
line1, name, numbers	68.4	73.7	89.5	0.802	0.459
line1, name, rectangles	67.1	74.8	85.0	0.787	0.526
line1, name, rey	68.1	75.0	85.5	0.791	0.596
line1, name, rhombus	70.3	74.6	91.3	0.815	0.546
line1, name, signature	70.0	74.2	91.7	0.816	0.551

Continued on next page

Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
line1, name, spiral	66.7	75.3	82.7	0.783	0.584
line1, name, spiraltemplate	68.7	76.4	86.4	0.801	0.536
line1, numbers, rectangles	70.2	73.7	92.5	0.814	0.539
line1, numbers, rey	74.6	78.6	92.8	0.844	0.633
line1, numbers, rhombus	71.1	75.3	92.7	0.826	0.440
line1, numbers, signature	69.5	74.1	90.7	0.812	0.520
line1, numbers, spiral	69.9	72.1	94.6	0.813	0.546
line1, numbers, spiraltemplate	64.7	70.7	87.6	0.770	0.442
line1, rectangles, rey	70.8	78.1	85.3	0.809	0.617
line1, rectangles, rhombus	67.5	74.4	86.9	0.794	0.444
line1, rectangles, signature	70.9	75.0	91.8	0.821	0.505
line1, rectangles, spiral	72.0	74.6	94.5	0.830	0.532
line1, rectangles, spiraltemplate	69.8	73.8	91.3	0.811	0.515
line1, rey, rhombus	68.4	74.6	86.1	0.792	0.580
line1, rey, signature	71.3	75.0	92.5	0.824	0.549
line1, rey, spiral	70.6	72.4	95.4	0.818	0.555
line1, rey, spiraltemplate	64.7	75.0	81.1	0.770	0.541
line1, rhombus, signature	71.7	73.9	94.7	0.827	0.542
line1, rhombus, spiral	74.5	75.9	96.6	0.847	0.590
line1, rhombus, spiraltemplate	69.0	75.7	87.6	0.805	0.464
line1, signature, spiral	73.7	76.9	94.0	0.843	0.544
line1, signature, spiraltemplate	70.7	75.1	90.9	0.818	0.514
line1, spiral, spiraltemplate	67.5	73.8	87.1	0.791	0.549
line2, name, numbers	70.7	73.3	91.6	0.810	0.409
line2, name, rectangles	68.3	72.6	90.7	0.802	0.484
line2, name, rey	69.7	73.6	91.6	0.812	0.461
line2, name, rhombus	68.6	71.2	92.1	0.798	0.522
line2, name, signature	68.7	74.6	87.9	0.801	0.511
line2, name, spiral	70.8	75.0	92.5	0.822	0.447
line2, name, spiraltemplate	63.4	69.3	85.9	0.758	0.473
line2, numbers, rectangles	67.8	71.4	89.6	0.788	0.398
line2, numbers, rey	73.9	75.9	95.4	0.841	0.452
line2, numbers, rhombus	68.8	72.5	90.6	0.797	0.459
line2, numbers, signature	69.3	73.8	91.4	0.808	0.438
line2, numbers, spiral	72.3	73.9	96.6	0.834	0.453
line2, numbers, spiraltemplate	68.3	72.5	90.7	0.800	0.371
line2, rectangles, rey	68.5	73.2	90.0	0.802	0.535
line2, rectangles, rhombus	67.8	75.3	86.1	0.797	0.480

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
line2, rectangles, signature	61.9	71.5	78.9	0.743	0.443
line2, rectangles, spiral	63.4	70.5	83.6	0.757	0.418
line2, rectangles, spiraltemplate	58.2	68.3	75.4	0.702	0.371
line2, rey, rhombus	61.9	70.9	79.9	0.742	0.440
line2, rey, signature	72.6	75.3	95.2	0.836	0.478
line2, rey, spiral	67.4	70.4	90.6	0.788	0.452
line2, rey, spiraltemplate	67.1	70.0	90.1	0.782	0.405
line2, rhombus, signature	71.1	75.6	90.2	0.817	0.497
line2, rhombus, spiral	67.9	71.2	90.1	0.789	0.464
line2, rhombus, spiraltemplate	70.4	74.6	92.1	0.819	0.452
line2, signature, spiral	60.6	66.8	74.2	0.696	0.388
line2, signature, spiraltemplate	59.2	65.7	70.8	0.674	0.403
line2, spiral, spiraltemplate	62.1	71.9	77.9	0.739	0.383
name, numbers, rectangles	62.0	70.3	83.2	0.755	0.420
name, numbers, rey	67.2	70.9	88.3	0.781	0.525
name, numbers, rhombus	66.2	72.2	87.5	0.786	0.485
name, numbers, signature	63.3	70.3	83.2	0.755	0.520
name, numbers, spiral	68.5	72.6	89.2	0.796	0.528
name, numbers, spiraltemplate	65.5	69.6	90.0	0.780	0.468
name, rectangles, rey	63.7	70.1	84.7	0.760	0.503
name, rectangles, rhombus	60.7	68.4	79.4	0.727	0.461
name, rectangles, signature	61.3	70.8	77.2	0.733	0.458
name, rectangles, spiral	64.4	71.9	82.0	0.759	0.486
name, rectangles, spiraltemplate	62.1	67.4	84.6	0.744	0.457
name, rey, rhombus	68.2	73.0	89.3	0.798	0.576
name, rey, signature	65.2	72.4	83.9	0.769	0.543
name, rey, spiral	64.3	69.7	85.5	0.762	0.555
name, rey, spiraltemplate	64.8	70.0	83.6	0.755	0.514
name, rhombus, signature	63.5	70.6	82.9	0.756	0.516
name, rhombus, spiral	68.5	73.9	87.5	0.795	0.581
name, rhombus, spiraltemplate	65.8	70.0	89.7	0.780	0.480
name, signature, spiral	63.7	71.6	82.3	0.757	0.528
name, signature, spiraltemplate	65.2	72.0	84.5	0.771	0.532
name, spiral, spiraltemplate	64.6	73.0	79.3	0.752	0.525
numbers, rectangles, rey	63.9	70.8	83.8	0.762	0.513
numbers, rectangles, rhombus	69.3	74.6	86.5	0.795	0.577
numbers, rectangles, signature	63.1	72.2	79.6	0.751	0.511
numbers, rectangles, spiral	68.5	74.0	86.5	0.791	0.565

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Table C.1 – continued from previous page

Task combination	Accuracy [%]	Precision [%]	Recall [%]	F1	AUC
numbers, rectangles, spiraltemplate	61.0	66.5	83.4	0.734	0.448
numbers, rey, rhombus	67.4	70.9	90.2	0.790	0.562
numbers, rey, signature	67.0	74.8	83.0	0.779	0.553
numbers, rey, spiral	70.1	74.1	89.4	0.805	0.616
numbers, rey, spiraltemplate	64.6	68.1	88.8	0.765	0.438
numbers, rhombus, signature	67.7	74.8	83.5	0.784	0.579
numbers, rhombus, spiral	72.1	76.8	87.0	0.810	0.616
numbers, rhombus, spiraltemplate	69.2	76.2	84.7	0.797	0.565
numbers, signature, spiral	70.0	76.4	84.3	0.795	0.625
numbers, signature, spiraltemplate	63.0	74.8	75.6	0.745	0.512
numbers, spiral, spiraltemplate	65.7	72.8	83.1	0.771	0.540
rectangles, rey, rhombus	68.9	73.9	86.6	0.791	0.615
rectangles, rey, signature	66.0	71.8	85.1	0.774	0.490
rectangles, rey, spiral	68.6	71.8	90.6	0.796	0.608
rectangles, rey, spiraltemplate	62.8	66.6	87.9	0.750	0.532
rectangles, rhombus, signature	68.5	75.5	83.4	0.787	0.611
rectangles, rhombus, spiral	74.8	80.5	85.9	0.828	0.668
rectangles, rhombus, spiraltemplate	68.7	74.9	84.6	0.790	0.596
rectangles, signature, spiral	67.3	75.3	79.1	0.767	0.628
rectangles, signature, spiraltemplate	64.8	73.5	76.7	0.744	0.554
rectangles, spiral, spiraltemplate	66.1	73.9	80.6	0.765	0.564
rey, rhombus, signature	68.5	73.6	86.5	0.788	0.634
rey, rhombus, spiral	75.9	77.9	91.9	0.839	0.705
rey, rhombus, spiraltemplate	65.0	70.0	85.1	0.763	0.548
rey, signature, spiral	66.9	72.8	86.1	0.782	0.579
rey, signature, spiraltemplate	63.9	69.7	86.6	0.768	0.479
rey, spiral, spiraltemplate	64.2	70.0	83.6	0.756	0.549
rhombus, signature, spiral	69.2	75.3	84.6	0.792	0.625
rhombus, signature, spiraltemplate	69.9	76.5	85.1	0.800	0.628
rhombus, spiral, spiraltemplate	71.3	76.3	86.8	0.807	0.642
signature, spiral, spiraltemplate	67.3	78.1	77.0	0.770	0.592

Table C.1: Results PD classification with spectral features

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