




An Information System for Training Assessment in Sports Analytics

Vanessa Meyer¹ ^a, Lena Wiese¹ ^b and Ahmed Al-Ghezi¹ ^c

¹*Institute of Computer Science, Goethe University Frankfurt, Robert-Mayer-Str. 10, 60325 Frankfurt am Main, Germany
v.meyer@em.uni-frankfurt.de, {lwiese, alghezi}@cs.uni-frankfurt.de*

Keywords: Sport Data Analytics, Human Activity Recognition, Data Visualization

Abstract: This paper presents an information system that analyzes and visualizes sports and human activity data. Clustering is used to divide data into groups; however, the wide variation in methods for data preprocessing and clustering makes it difficult to decide on appropriate methods. Thus, for the analysis of clustering methods, we comparatively evaluate methods for preprocessing the data in addition to the different methods for clustering. In addition, our sports analytics information system provides an approach that is able to assign athletes to a cluster based on their individual features and hence provides an individual training assessment compared to the clusters obtained on the data. The proposed visualization approach in comparison to a certain cluster offers an intuitive solution for assessing the goodness of fit.


1 INTRODUCTION


Every day, a large amount of information is retrieved and stored. To evaluate data, it has always been of particular importance for people to compare things or phenomena with each other based on their similarity, to learn unknown patterns (Xu and Wunsch, 2005). The similarity-based grouping of data plays a major role in this kind of evaluation: the goal of clustering methods is to find groups of similar data objects in data sets (Bishop and Nasrabadi, 2006). As an unsupervised learning methods, unlike supervised learning methods, there is no need for labeled target variables in clustering. Hence, we can conveniently base our analysis only input variables.


Advances in modern communication technologies (through portable, mobile devices and “wearables”) have made the areas of “individualized training monitoring” and “smart health” a central part of modern life in order to improve athletic performance and individual health. In addition to these continuously collected monitoring data, there are also conventional data collected from laboratory tests (genomics, blood values) or questionnaires (mental health). Very complex data sets are therefore available in the area of sports and health, covering different modalities and granularities. From an economic perspective, the sports sector is a key growth market: “The sport-

tech industry has experienced and is expected to experience exceptional growth with a compound annual growth rate of more than 20% between 2018 and 2024” (Frevel et al., 2020). The ISPO (International Trade Fair for Sporting Goods and Sports Fashion) even speaks of “an increase of 60 percent to around €82.3 million” in spending on fitness apps in Germany in the year 2020¹. The marketable goal of our sports information system is to create personalized recommendations for improvements in training and health status. This is based on the analysis of clusters/cohorts of similar athletes and the training recommendations that could be derived from them. As a long-term vision such an information system may also support commercial applications, for example for manufacturers of fitness equipment – especially in combination with mobile devices (smart watches or fitness trackers connected to corresponding apps).

Contributions. Extending our previous work (Meyer et al., 2023), we present an information system to find prototypical features in sports data using clustering techniques while optimizing associated methods for preprocessing the data. Our use case is a personalized assessment of the training status of individuals in this sports information system. To illustrate our system, a public data set is used for testing: the Multilevel Monitoring of Activity and Sleep in Healthy people (MMASH) data set (Rossi et al.,

^a  <https://orcid.org/0009-0006-3394-6291>

^b  <https://orcid.org/0000-0003-3515-9209>

^c  <https://orcid.org/0000-0002-1683-0629>

¹<https://www.ispo.com/en/topic/sportstech>

2020a; Rossi et al., 2020b) available via Physionet (Goldberger et al., 2000). The data set is pre-processed accordingly before clustering, where different variants of method combinations are tested here. Furthermore, the following well-known clustering methods are used: K-Means, Hierarchical Clustering, Density-Based Spatial Clustering of Applications with Noise (DBSCAN), Affinity propagation, Mean-shift and Balanced Iterative Reducing and Clustering using Hierarchies (BIRCH). By choosing different clustering methods and preprocessing methods, the differences between each method and the resulting influence on the clustering results are clarified.

In addition, we present the user interface of our system where users can create their visual profiles based on selected features. For the self-assessment, their own measurement values for selected features can be entered. Based on the entered values an assignment to a group is made, as well as a presentation of the differences between the own features and the features of other individuals belonging to the cluster.

Outline. Section 2 includes related works with different applications of data mining and clustering in sports. Section 3 presents the MMASH dataset; this is followed by a description of the steps used to preprocess the data. In Section 4 six different clustering methods as well as three cluster validation indexes are described. Furthermore, the section compares and interprets the quality of the clusters formed by the various clustering methods. Afterwards, Section 5 presents a web user interface. Here the user can select a dataset to create a visual profile based on selected features. In a final conclusion, Section 6 provides an outlook for future research.

2 RELATED WORK

Related works are surveyed in the following that deal with clustering or other methods from the field of data mining in sports. The related works show quite different goals and applications of data mining techniques: prediction of sports match results, performance improvement of individual athletes or teams, or determination of the market value of athletes or teams. According to (Cao, 2012), in the past, sports organizations relied on the experience of individuals such as coaches or players. Over time, however, the amount of data collected has increased, making the use of methods such as data mining increasingly important. In (Cao, 2012) a model is presented that focuses on the prediction of scores of an NBA game; it is intended to develop strategies in advance or can be con-

sidered for sports betting. Logistic Regression, SVM, Artificial Neural Networks and Naïve Bayes are used, and the accuracy of prediction of the mentioned models in is considered most important.

In (D’Urso et al., 2022), a fuzzy cluster model is proposed that can be applied to different types of variables, so-called mixed data from the field of sport. The mixed data are, among others, quantitative, nominal and time series data. Suitable dissimilarity measures are calculated for each variable, which are given weights during the clustering process, as each variable has a different relevance for the results. Through a simulation study, it was shown that the model can handle outliers and assign correct weights to the distance matrices. The authors apply the proposed cluster model to data of football players that include both performance and positional characteristics.

A clustering algorithm is also used in (Narizuka and Yamazaki, 2019). The focus of this work is on team sports, specifically football matches. The method divides formations of the games into several average formations, which are again divided into specific patterns, so that the formations are clustered across several games. The methods used in this work are hierarchical clustering and the Delaunay method. The data used is from J1 league football matches. According to the authors, the method provides a tool for formation analysis and characterizing and thus recognizing team styles in the respective sport.

K-Means clustering was used in (Shelly et al., 2020) to divide the data collected with wearables from athletes in the sport of American football into training groups. The formation of the training groups was based on the individual playing requirements of the athletes. According to the authors, the results of the analysis were confirmed when compared to traditional groupings for training in American football.

The focus in (Fister et al., 2020) is on individual sports, such as running, cycling or triathlon, where the time achieved is important for the quality of the results. The authors review recent solutions regarding post-hoc analysis. In this context, they mention performance analysis, physical characteristics and athletes’ behavior after a race. In their paper, the authors achieve a robust solution based on heart rate data. It could help athletic trainers advise their athletes to further improve their performance and was tested on two case studies of running athletes.

(Li et al., 2022) develop a model to assess the physical fitness of athletes, in addition to a recommendation model. Results from an experiment show a higher classification accuracy compared to classical methods. The authors estimate the application value, research value and market application prospects for

monitoring human fitness using the presented methods to be high. In addition, the assessment method obtained could be used to strengthen physical training in a targeted manner.

For prediction of the performance of trainings in sports, (Li, 2022) use a generative adversarial neural network algorithm. Behavioral characteristics of students are extracted; using a maximum pooling method, the salient features of students are selected. For prediction, the extracted features are subsequently used as input to the neural network.

From an information system perspective, only few related studies exist. From a physical education point of view of pupils, (Feng, 2023) set up a web-based system that applies a Decision Tree (DT) Classifier for data mining.

More generally, (Herberger and Litke, 2021) provide a literature survey with a focus on professional football; while not describing any technical applications in detail, the authors discuss pros and cons of sports data analytics.

For the purpose of general athlete monitoring (Thornton et al., 2019) survey some statistical approaches with a focus on individual’s data (so-called “within-athlete changes”) with respect to training load. Similarly, (Sarlis et al., 2023) analyze injury-induced impact on performance in professional basketball; whereas (de Leeuw et al., 2023) discuss the impact of internal and external training load on recuperation and devise a specific heart rate model for professional road cycling.

As opposed to these related works, in this paper we particularly focus on clustering as a data mining tool and present an intuitive user interface.

3 DATA PREPROCESSING

3.1 Data Set

For test purposes we use the publicly accessible Multilevel Monitoring of Activity and Sleep in Healthy people (MMASH) data set, which is presented in (Rossi et al., 2020b) and can be downloaded on the PhysioNet page (Goldberger et al., 2000). The MMASH data set can be assigned to the field of sports and was published through the Open Database License (ODbL). The authors of (Rossi et al., 2020b) describe the MMASH data set as the first public data set that offers psycho-physiological features on such a scale. Accordingly, there are already other data sets with data such as long-term heartbeat data, but not in connection with actigraph or psychological data. The MMASH data set contains information over a 24-hour

period of continuous measurements, including measurements of time intervals between heart beats, heart rate measurements, and others. The data, collected by the company BioBeats and researchers from the University of Pisa, includes data from a total of 22 participants, who are adults, male and mainly students at the University of Pisa. According to the authors of (Rossi et al., 2020b), this represents a sample that is as homogeneous as possible. There are 7 files for each participant with a total of 61 features.

3.2 Preprocessing

Prior to clustering, the MMASH data set is preprocessed to obtain data in a suitable form for the chosen clustering procedures. (Kirchner et al., 2016), point out the importance of preprocessing data before applying clustering algorithms. According to the authors, finding appropriate methods for preprocessing and their execution order is challenging. Therefore, in this paper, three different variants of preprocessing data are used to later show the impact of preprocessing on clustering results.

Table 1: Three versions of preprocessing pipelines for MMASH data

	Version 1	Version 2	Version 3
Missing Values	fill with mean	fill with mean	replace with 0
Feature Selection	Pearson Correlation	PCA	Pearson Correlation (different threshold)
Scaling	MinMax	Standard	MinMax

Before the preprocessing methods can be applied to the MMASH data set, the data are first transformed into a form suitable for the scikit-learn implementations² of the various clustering methods. Since time series data are not considered in this paper, attributes are transformed or aggregated accordingly. In addition, the original data (Rossi et al., 2020b; Rossi et al., 2020a; Goldberger et al., 2000) are split into different files for each participant. Finally, to put the data for the clustering algorithms into a form where the values of all participants are in one .csv file and in it each row represents the attributes of an individual participant, the files are merged into one remaining file.

The first step of data preprocessing is finding missing values and dealing with them. In the first two

²<https://scikit-learn.org/stable/modules/clustering.html>

versions, missing values are replaced with the corresponding mean values of the attributes. In the third version, missing values are replaced with the value 0. Outlier detection is not applied to the MMASH data, since the data set contains very few data objects anyway and without further domain knowledge it is not possible to assess whether any outliers found are really outliers. Subsequently, the dimension of the data sets is reduced with respect to the number of attributes. In the first version, a subset of the features is created using the Pearson correlation and a set threshold, in which features with higher correlation were removed. In the second version, Principal Component Analysis (PCA) is used. In the third version, subsets are again created using Pearson correlation, this time setting a different threshold. To scale the data, in the first and third versions the MinMaxScaler, which scales the values between 0 and 1 (0 is the minimum of the values and 1 is the maximum of the values of an attribute). In the second version, the StandardScaler is used. Implementations³ of scikit-learn were used for the scaling methods.

4 CLUSTERING ANALYSIS

After the data has been preprocessed, clustering divides the data into groups. Subsequently, the resulting clusters are visualized and evaluated using internal cluster indices. At the end, individual clusters are described and interpreted.

4.1 Clustering Methods

- **K-Means:** A well-known partitioning method is the K-means clustering method. In the K-means method, parameter k is determined at the beginning, where k is the number of groups to which the individual data objects are to be assigned. To determine the membership of the data objects in the clusters, so-called centroids are determined for each cluster and then each data object is assigned to the cluster whose centroid is closest to the data object. The dispersion of the overall within-cluster is minimized by the iterative redistribution from the cluster members. In high-dimensional spaces, however, these algorithms do not show a good effect. This is because in high-dimensional spaces almost all pairs of points are as far away as the average. Thus, the distance concept is poorly defined in high-dimensional spaces.

³https://scikit-learn.org/stable/auto_examples/preprocessing/plot_all_scaling.html

Another disadvantage is that the number of clusters to be formed must be specified by the user in advance. In addition, partitioning methods are sensitive to initialization, as well as to noise and outliers. Partitioning methods also often get entangled in local optima. Non-convex clusters of different sizes or densities cannot be handled by partitioning methods like k-means.

- **Hierarchical Clustering:** In contrast to partitioning algorithms such as k-means, hierarchical clustering combines or splits existing clusters. This creates a hierarchical structure that contains the order in which the clusters are combined or divided. The combination of clusters takes place in the agglomerative approach of hierarchical clustering. In this approach, the individual data objects initially belong to their own cluster, each of which contains only the one data object. Thus, initially there are the clusters S_1, S_2, \dots, S_n with n as the number of data objects. Subsequently, a cost function is to find pairs $\{S_i, S_j\}$ that are to be combined into a cluster at minimum cost. Thus S_i and S_j are removed from the list of existing clusters and a new cluster $S_i \cup S_j$ is added. This procedure is repeated until there is only one cluster that contains all data objects. As for the cost function, there are several variants such as complete linkage (take maximum distance between members of two clusters), average linkage (take average distance between members of two clusters) and single linkage (take minimum distance between members of two clusters). Hierarchical procedures have the disadvantages that once the decision to split or merge groups has been made, no corrections can be made, that there are poorly interpretable cluster descriptors, and that the termination criterion of this method is undefined. Hierarchical methods are less effective in high dimensional spaces due to the curse of dimensionality.
- **DBSCAN:** In contrast to the k-means algorithm, which assumes a convex shape of the clusters, in DBSCAN all shapes of clusters can occur. This is because in DBSCAN the clusters are formed in such a way that points from a high-density area are in one cluster. Points that are in high density areas are also called core samples. Thus, a cluster is a set of these core samples. For the DBSCAN algorithm, two parameters must be set. One parameter is the minimum number of neighbor points (*min_samples*) to call a point a core sample. The second parameter that must be set is *eps(ilon)*. With *eps* the distance is specified in which the neighbors of a core sample are located. For forming clusters with a larger minimum num-

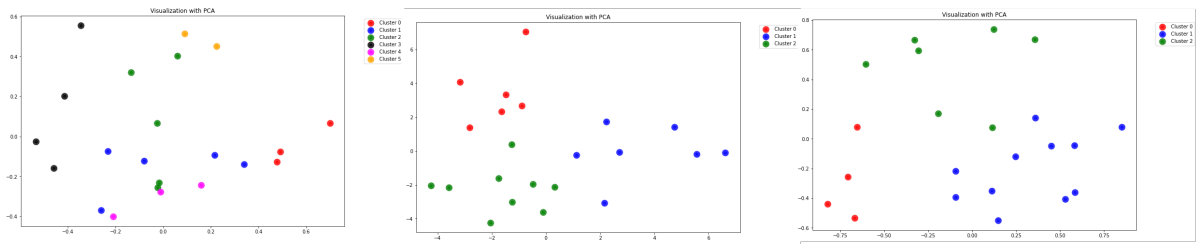


Figure 1: Resulting k-means clusters of the different data set variants (V1, V2, V3).

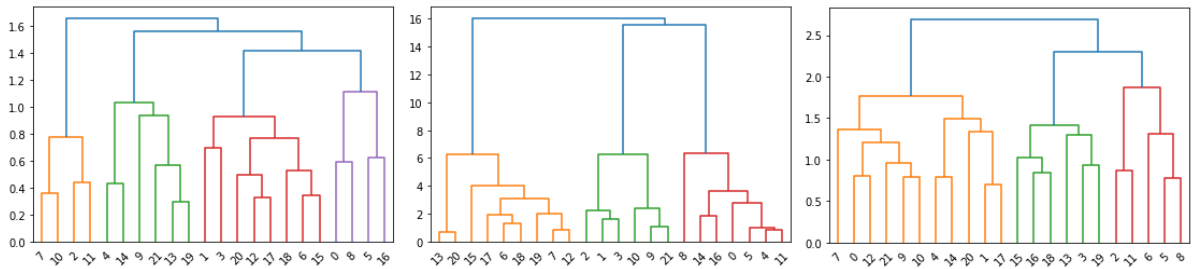


Figure 2: Dendrograms of the different data set variants (V1, V2, V3).

ber of neighbors or small eps , a higher density is needed. DBSCAN starts with a random core sample and finds all its neighbors that are also core samples. The neighboring core samples are added to the cluster and recursively all neighboring core samples of these newly added core samples are added to the cluster. Neighboring non-core samples that are in the neighborhood of core samples are also added to the cluster, but no other neighbors of non-core samples are added. These Non-core samples that are near to core samples and thus added to a cluster are border points of the clusters. Non-core samples that are not in the neighborhood of core-samples are outliers. All core-samples, however, belong to a cluster. If eps is too small, many points are marked as outliers with the value -1. If eps is too large, it happens that all points are assigned to just one cluster. So, it is important to choose an appropriate value for the parameter eps . Advantages of density-based cluster algorithms are that arbitrarily shaped clusters can be found, the clusters found can be of different sizes, and their resistance to noise and outliers. Disadvantages are the high sensitivity to the parameters that must be set by the user.

- **Affinity Propagation:** In affinity propagation, messages are exchanged between pairs of samples. These exchanged messages indicate whether a sample is suitable as an exemplar for the other sample. Based on the responses to values of other pairs, the suitability is iteratively updated until convergence is reached. Once convergence is reached, the final clusters are formed. Based on

the given data, the number of clusters to be formed is determined. The parameters that are important for affinity propagation are firstly the preference and secondly the attenuation factor. The preference controls the number of copies to be used. To avoid numerical fluctuations when updating the responsibility and availability messages, the said messages are damped with the damping factor. Due to the complexity affinity propagation should rather be used for small to medium sized data sets.

- **Mean-Shift:** Mean-Shift is a center-based algorithm that aims to find blobs in a uniform density of samples. In this process, candidate centers are updated. This updating is done by having the candidate centers represent the mean of the points in a region. Finally, the centers are formed by filtering the candidates in a post-processing phase to remove near-duplicates. The number of clusters to be formed is determined by the algorithm. Since the Mean-shift algorithm requires multiple nearest neighbor searches, it is not highly scalable. In addition, Mean-shift stops iterating at only slight changes in centroids, but is guaranteed to converge. Labeling of the new samples is done according to the nearest centroid.
- **BIRCH:** In BIRCH, a feature tree is created, where the data is compressed into cluster feature (CF) nodes containing so-called feature sub-clusters (CF subclusters). CF subclusters, which belong to non-terminal CF nodes, can have CF nodes as children. The CF subclusters contain information such as the number of samples in a subcluster, the linear sum, squared sum, centroids,

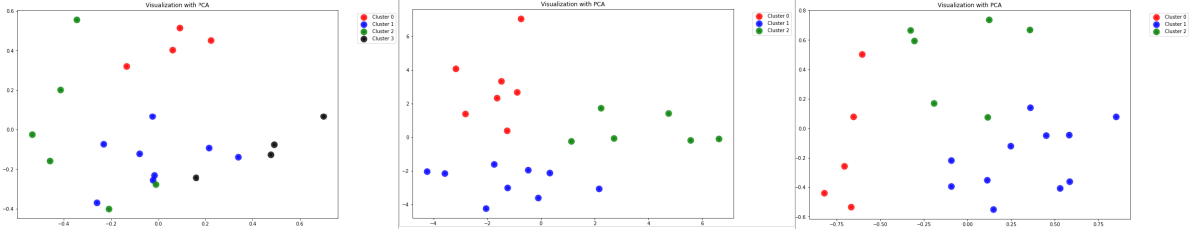


Figure 3: Resulting hierarchical clusters of the different data set variants (V1, V2, V3).

and the quadratic norm of the centroids. Thus, not all input data need to be held in memory. The input data is reduced to subclusters in BIRCH. Therefore, this algorithm can also be used as an instance or data reduction method before feeding reduced data into a global clusterer.

4.2 Cluster Validation

After presenting some cluster algorithms, the next step shows cluster validation indices (CVIs), which are used and compared to measure the goodness of the formed clusters. CVIs are used to combine compactness and separability of clusters. Compactness measures the closeness of cluster elements within a cluster (variance as a common measure) and separability measures the distance between two different clusters. In the following, some cluster validation indices are presented based on (Rendón et al., 2011).

- **Silhouette Coefficient (SC)**

The Silhouette coefficient is one of the evaluation methods where the evaluation is performed using the model itself when the ground truth labels are not present. The higher the Silhouette Score, the better defined the clusters are considered. For each sample of the dataset, the Silhouette Coefficient is defined by calculating the mean distance between the sample and all other samples of the same cluster (denoted as a in the formula below) and the mean distance between a sample and all other samples that are in a different, closest cluster (denoted as b in the formula below). The following formula describes the SC s for a sample:

$$s = \frac{b - a}{\max(a, b)} \quad (1)$$

To obtain the SC for multiple samples, the average of the individual silhouette coefficients of the samples is calculated. The application of the described SC is usually done on the results of a cluster analysis. The SC can take values between -1 and 1. If the SC is around zero, this indicates overlapping clusters. Higher values represent denser

and more distant clusters. A disadvantage is of the SC is that higher values are calculated for convex clusters. Non-convex clusters, which can occur in DBSCAN, for example, have a lower SC.

- **Calinski Harabasz (CH) Index**

The Calinski-Harabasz index, also called the Variance Ratio Criterion, can also be used for data sets where there are no ground truth labels. Again, a higher score indicates better defined clusters: If the clusters are of higher density and well separated, the CH score is higher. The Calinski-Harabasz index is used to represent the ratio of the sum of the dispersion between clusters and the dispersion within clusters:

$$s = \frac{\text{tr}(B_k)}{\text{tr}(W_k)} \times \frac{n_E - k}{k - 1} \quad (2)$$

with n_E as size of data set E , k as number of clusters, and traces tr of between-group dispersion matrix B_k and of within-cluster dispersion matrix W_k where:

$$W_k = \sum_{q=1}^k \sum_{x \in C_q} (x - c_q)(x - c_q)^T \quad (3)$$

with C_q set of points in cluster q and c_q center of cluster q and

$$B_k = \sum_{q=1}^k n_q (c_q - c_E)(c_q - c_E)^T \quad (4)$$

with c_E as the center of E and n_q as the number of points in cluster q . An advantage of this index is that the values of the index can be calculated quickly. A disadvantage is, as with the Silhouette Coefficient, that the values of the index are generally higher for convex clusters.

- **Davies Bouldin (DB) Index**

Analogous to the previous two validation scores, the Davies-Bouldin index is also used when no ground-truth labels are present. Unlike the Silhouette Coefficient and the Calinski-Harabasz Index, a lower Davies-Bouldin Index indicates that the clusters of a model are better separated. The

average ‘similarity’ is indicated by the Davies-Bouldin index, where this similarity is a comparison of the distance between clusters with the size of the clusters. The closer the values of the index are to zero, the better the partitioning is rated, with zero being the smallest possible and therefore best value. Advantages of the Davies-Bouldin index are that a simpler calculation is performed than with the Silhouette coefficient, and only pointwise distances are used for the calculation and, consequently, the index is based solely on sizes and features inherent in the data set. A disadvantage of this index is that the values are higher for convex clusters than for non-convex clusters. In addition, the distance metric is limited to Euclidean space since the center distance is used.

$$DB = \frac{1}{k} \sum_{i=1}^k \max_{i \neq j} R_{ij} \quad (5)$$

with

$$R_{ij} = \frac{s_i + s_j}{d_{ij}} \quad (6)$$

where s_i is the average distance between each point of cluster i and the centroid of cluster i and d_{ij} is the distance between centroids i and j .

4.3 Clustering Comparison

Clustering was applied to the different variants of the data set resulting from the three preprocessing pipelines. The results are compared with respect to the resulting clusters and cluster validation indices Silhouette Score (SC), Calinski Harabasz Score (CH) and the Davies Bouldin Score (DB). Based on the results determined by the cluster validation indices, the best possible clusters will be described and interpreted in more detail to perform cluster profiling.

- **K-means:** Before applying the k-means clustering procedure to the MMASH dataset and the body performance dataset, a suitable number of clusters k is first determined using the elbow method. First, k-means is applied to the MMASH dataset with preprocessing version 1. For this version, the elbow method results in a number $k = 6$ of clusters. In contrast, for the other two preprocessing versions of the MMASH dataset, only three clusters were formed. This shows that already the results of the elbow method are influenced by the way of preprocessing the data. In the two-dimensional visualizations in Fig 1, which are formed with the PCA method, it is also evident that depending on the version, the data points are arranged differently in the coordinate system.

Hence, the components formed by PCA differ depending on the version. The number of data objects in the respective cluster is shown in Table 2.

Table 2: Number of data points in the respective k-means clusters for each data set variant.

Data Set	Cl. 0	Cl. 1	Cl. 2	Cl. 3	Cl. 4	Cl. 5
MMASH V1	3	5	5	4	3	2
MMASH V2	6	7	9	-	-	-
MMASH V3	4	11	7	-	-	-

- **Hierarchical Clustering:** To find a suitable number of clusters for Hierarchical Clustering, dendrograms were first considered. The groups highlighted in color in the dendrograms (Fig. 2) were used as orientation for setting the number of clusters. In this way, for the first MMASH version, four groups were created in the hierarchical clustering. However, for the other two versions of the MMASH dataset, three groups were created in each case. Again, the PCA method results in different arrangements of the data points in the coordinate system depending on the preprocessing version: Fig. 3 again shows the visualizations of the resulting clusters of the hierarchical clustering for the MMASH dataset. The number of data objects in the respective cluster is shown in Table 3.

Table 3: Number of data points in the respective hierarchical clusters.

Data Set	Cl. 0	Cl. 1	Cl. 2	Cl. 3
MMASH V1	4	8	6	4
MMASH V2	7	9	6	-
MMASH V3	5	11	6	-

- **DBSCAN:** In contrast to k-means and hierarchical clustering, DBSCAN does not initially specify a number for the groups to be formed as a parameter. Here, the groups are formed during the run of the algorithm. Given $eps = 0.6$ and $min_samples = 2$, two clusters are created for the first version of the MMASH dataset. For the second version of the MMASH dataset, $eps = 2$ was set. The value of $min_samples = 2$ was also used here. This created four clusters in the second version. The parameters of the third preprocessing version of the MMASH dataset were set to $eps = 0.9$ and $min_samples = 2$. Again, as in version 2, four clusters were formed. The number of data objects in the respective cluster is shown in Table 4.
- **Affinity Propagation:** As with DBSCAN, no pa-

Table 4: Number of data points in the DBSCAN clusters.

Data Set	Noise	Cl. 0	Cl. 1	Cl. 2	Cl. 3
MMASH V1	3	2	17	-	-
MMASH V2	2	6	3	8	3
MMASH V3	6	4	5	5	2

parameter for the number of clusters is set for affinity propagation. In the first version of the MMASH dataset, five clusters were formed by affinity propagation. In contrast, four clusters were formed in each of the other two versions. In version 1 and version 3, overlaps are also evident in some of the clusters in the visualizations. Table 5 shows the number of data points assigned to each cluster.

Table 5: Number of data points in the affinity propagation clusters.

Data Set	Cl. 0	Cl. 1	Cl. 2	Cl. 3	Cl. 4
MMASH V1	2	5	6	4	5
MMASH V2	4	7	8	3	-
MMASH V3	9	4	4	5	-

- Mean-Shift: Mean-shift also does not require the user to specify the number of clusters. In version 1 and version 2 of the MMASH dataset, five clusters were formed using mean-shift. In the third version of the MMASH dataset, however, only three clusters were generated using mean-shift. It can be seen that imbalanced clusters were formed that included very many versus very few samples. The number of samples in the respective cluster is shown in Table 6.

Table 6: Number of data points in the mean-shift clusters.

Data Set	Cl. 0	Cl. 1	Cl. 2	Cl. 3	Cl. 4
MMASH V1	15	3	2	1	1
MMASH V2	9	6	3	3	1
MMASH V3	20	1	1	-	-

- BIRCH: With BIRCH, as with k-means and hierarchical clustering, the number of clusters is chosen by the user. For the MMASH dataset, four clusters were selected as a parameter for each of the first two preprocessing versions. For the third version, the parameter for the number of clusters is set to three. Table 7 shows the respective cluster size based on the point assignment.

The individual results of the cluster validation indices (CVI) are given in Table 8 for each cluster algorithm and each version of the preprocessing.

Table 7: Number of data points in the BIRCH clusters.

Data Set	Cl. 0	Cl. 1	Cl. 2	Cl. 3
MMASH V1	4	8	6	4
MMASH V2	6	9	6	1
MMASH V3	5	11	6	-

Table 8: Evaluation of different cluster algorithms that were applied to three versions of preprocessed MMASH dataset.

Algorithm	CVI	V1	V2	V3
K-means	SC	0.2165	0.4483	0.1568
	CH	5.4768	24.6601	4.6403
	DB	1.1433	0.6833	1.6557
Hierarchical	SC	0.1868	0.4674	0.1410
	CH	5.3219	24.4796	4.4898
	DB	1.3433	0.6445	1.6918
DBSCAN	SC	0.0768	0.3822	0.0855
	CH	2.2100	10.5337	2.7669
	DB	1.8793	2.2796	1.8158
Aff. Prop.	SC	0.1732	0.4185	0.0857
	CH	4.5213	22.2652	3.0880
	DB	1.2958	0.7266	1.7820
Mean-Shift	SC	0.0068	0.4026	0.0264
	CH	2.3804	21.4384	1.5655
	DB	1.1292	0.5548	0.7846
BIRCH	SC	0.1868	0.4293	0.1410
	CH	5.3219	20.9996	4.4898
	DB	1.3433	0.5476	1.6918

Silhouette Score: The calculated silhouette scores for the MMASH dataset are in the positive range for all three preprocessing combinations and all cluster algorithms. However, the scores for all three results are closer to the 0 value rather than the 1 value, indicating that there are partially overlapping clusters. Especially the silhouette score of version 3 is very low and closest to 0. This could be related to the fact that more features were retained in this version than in the other two versions and thus the dimension of the dataset is larger and affects the goodness of clusters. Version 2 overall has the best silhouette scores. If only version 1 is considered and the values of the different cluster algorithms are compared, k-means has the highest and thus best silhouette score for version 1. In the second version, the silhouette score for hierarchical clustering is the highest compared to the other cluster algorithms. As in version 1, k-means is also in first place in version 3 with respect to the silhouette score.

Calinski Harabasz Score: Overall, k-means provides the highest and thus best Calinski Harabasz score for version 2. If only version 1 is considered, k-means is also the algorithm that produces the highest score for this version of the MMASH dataset compared to the other cluster algorithms. For the third ver-

sion, the k-means algorithm also produces the highest Calinski Harabasz score, although this is somewhat lower than for version 1.

Davies Bouldin Score: For the Davies Bouldin score, smaller values represent better separated resulting clusters. The closer the value is to zero, the better. The smallest and therefore best Davies Bouldin score for the MMASH dataset was achieved by the BIRCH algorithm applied to version 2. For version 1 and version 3, mean-shift produced the smallest score.

5 IMPLEMENTATION

5.1 Description of the Streamlit App

Our Streamlit web application aims to analyze data using the K-Means clustering algorithm. Users have the option to upload a CSV file to our application. After uploading a CSV file, various options are available to pre-process the data. This includes in particular measures such as dealing with missing values and the selection of features. It is also possible to scale selected features. In addition, users can enter their own data in additional fields in order to be assigned to a cluster based on the entered data after the clustering algorithm has been executed.

The libraries used in our implementation are now explained in more detail.

Streamlit: Streamlit⁴ is a Python library for building web applications. It is used to create our user interface and interact with users.

Pandas (Python data analysis): Pandas also belongs to the most used libraries in the field of Data Science and offers among other things the possibility to load CSV files and display them as a data frame. In our Streamlit application it is used to read and manipulate data from the CSV files uploaded by the user.

Matplotlib: Matplotlib is often used to visualize data. We use this library to create 2D plots that visualize the results of the k-means clustering algorithm.

Scikit-learn: The scikit-learn library contains many machine learning algorithms. Clustering and dimension reduction are among the applications of this library. In our case, it is used to perform K-Means clustering and scaling data. To do this, we specifically use `sklearn.cluster.KMeans`, `sklearn.cluster.k_means` and `sklearn.preprocessing.MinMaxScaler`.

⁴<https://docs.streamlit.io/>

NumPy (Numerical Python): NumPy is used for numerical calculations and is considered a fundamental package for this. NumPy provides tools for working with multidimensional objects (arrays) and is widely used in data analysis. Within our application it is used to work with arrays and numerical operations.

Plotly: The Plotly⁵ library can be used to create interactive graphs. In our streamlit application, plotly express is used to create radar charts for cluster display with multiple features.

Seaborn: Seaborn⁶ is based on matplotlib and is also used to visualize data. We rely on this library to provide a more attractive representation of data.

5.2 Data Preprocessing

After a CSV file has been successfully uploaded, the various options for pre-processing the data become visible. To ensure that an appropriate error message is displayed and the user can be informed if preprocessing steps are necessary before cluster analysis, the entire preprocessing is enclosed in a try-except block.

Handling missing values: Using the checkbox with the label *Handling missing values*, users of our application can choose how to handle missing values in the data set they uploaded. There are two options to deal with the corresponding missing values. On the one hand, missing values can be ignored, on the other hand, missing values can be replaced by the mean value. If the *Fill with mean* option is selected, the missing values in the entire data set will be replaced by the mean of the respective column. Another checkbox with the label *Replace 0 with mean* can be selected if cells that contain the value 0 should also be replaced with the mean value.

Feature selection: In the sidebar, below the *Handling missing values* selection fields, the features can be selected from a list of all available features that should be used for the cluster analysis. Selected features are stored in a separate data frame *selected_data*. The user can use the sidebar to choose whether the original data or the data with the selected features should be displayed using checkboxes. This means that users have access to the original data and the data with selected features at any time.

⁵<https://plotly.com/python/>

⁶<https://seaborn.pydata.org/>

Scaling the data: To ensure that all data have the same scale range, the user can choose to scale the data. If the *Scale data* checkbox is activated, the data is scaled using the min-max scaling from the Scikit-learn library. If the data has been scaled, it can also be displayed by activating the corresponding checkbox.

Entering individual data: Once the user has selected features that should be considered for cluster analysis, the user can enter their own values for the features. These values are used for assignment to one of the resulting clusters.

5.3 Cluster Assignment

After preprocessing the data and the user's feature input, the cluster analysis can be started. To do this, the user enters the desired number of clusters k and starts the cluster analysis by confirming the analysis button. The K-Means algorithm from the Scikit-learn library is run on the preprocessed data and the cluster centers are determined. In addition, the values entered by the user for the selected features are compared with the descaled cluster centers (if the data was previously scaled) so that the user can be assigned to one of the resulting clusters. In order to compare the data entered by the user with the calculated cluster centers and determine a cluster assignment, the minimum distance of the input vector to the cluster centers is calculated. To do this, the *np.linalg.norm* method is used, which calculates the Euclidean distance. The following code snippet shows the cluster assignment in more detail.

```
# Distances between input-vector and centers
dist = []
for center in centers_descaled:
    dist.append
        (np.linalg.norm(input_vector - center))
min_dist = min(dist)

assigned_Cluster = dist.index(min_dist)
```

The user's entered feature values were previously stored in an *input_vector* array. The *np.linalg.norm* function calculates the Euclidean distance between the input vector and the descaled cluster centers (*centers_descaled*). The array *dist* then contains the distances to each cluster center. *Min(dist)* is used to find the index of the minimum distance in *dist*. This index corresponds to the cluster that has the minimum distance to the input vector.

5.4 Visualization Techniques

The results of the K-Means cluster analysis should be displayed visually in order to give the user an intuitive

insight into the assignment to one of the clusters and to clarify the differences between the individual features and the cluster center features of the assigned cluster. This is intended to make the interpretation and analysis of the results easier. Radar charts and bar charts are used for the visualization, which illustrate the assignment to clusters and the differences to the cluster centers. Each selected feature is also represented by a gauge plot showing the difference between the entered values and the cluster center values.

If more than two features have been selected by the user, a radar chart is created using the plotly library. More specifically, *go.Scatterpolar* (where *go* stands for *plotly.graph_objects*) is also used to display the cluster centers and the user's input data as lines in the radar chart. In order to be comparable, the data is scaled to a common scale. In the case where only two or fewer features have been selected, a 2D bar chart is used to visualize the results. The bar chart is also created using the plotly library. Here *go.Bar* is used to display the cluster center bars and the user's input data. As with the radar chart, the data from the cluster centers and the inputs are scaled to a common scale.

After visualizing the associated cluster, the differences of each selected feature from those of the cluster center are shown using gauge plots using *go.Indicator*. In the following section, the visualizations are shown using a sports data set as an example.

To demonstrate the visualizations, we upload the MMASH data, which was previously converted into a suitable format, to our Streamlit application. As an example, five of the features were selected and the data was scaled. After starting the analysis, we get the following visualizations. Figure 4 shows the radar chart, in which the features of the cluster center (of the cluster to which the user was assigned to, based on the entered data) and the entered user data, which were brought to the same scale, are plotted. This means that several features can be viewed in direct comparison. However, in this type of visualization it is important that the values of all features are scaled, since otherwise features with generally much higher values will always be visually more pronounced in the radar chart and the features with generally lower values will be less pronounced in the radar chart.

In order to be able to view the differences between the user input and the cluster center with the actual (unscaled) values for each feature, gauge charts as shown in Figure 5 are used. The difference between the user input and the value of the cluster center can be read directly in the gauge charts. This makes it possible to quickly assess whether a specific user feature is above or below the value of the cluster center.

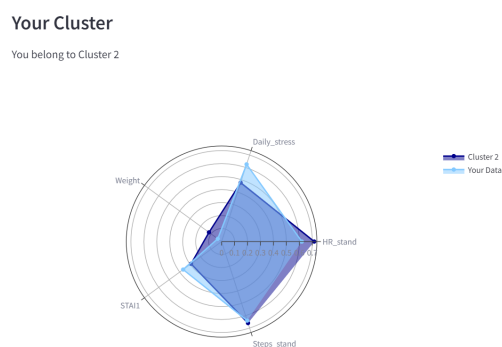


Figure 4: Visualization of a cluster and user characteristics using a radar chart.

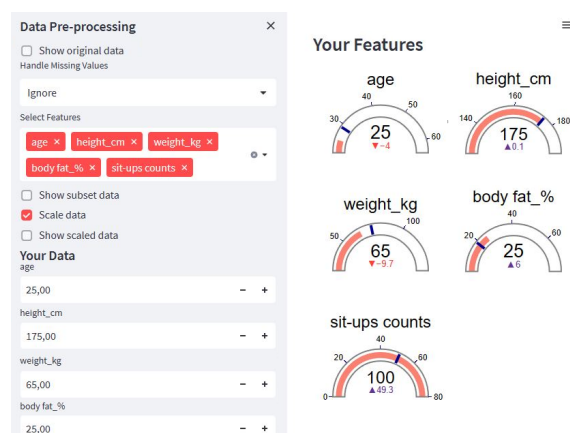


Figure 5: Visualization of cluster and user features using gauge charts.

6 CONCLUSIONS

Digitalization (supported by information systems) in the fields of sports and healthcare is a strong growth market (Schmidt, 2020) – especially through AI models, which make greater personalization and individualization possible in the first place. Individualization is a paradigm shift in sports analytics that is moving towards an individualized and fine-grained evaluation of performance and health status based on a cohort of similar athletes. The overall health of the athletes may be analyzed through comprehensive data analysis (laboratory tests, performance measurements, blood values, but also psychological questionnaires). Individualization leads to better use of training and performance resources on the one hand and reduces the negative side effects for athletes on the other. In this way, our sports information system promotes the innovation-driven use of data (taking multimodal data types into account) by not only creating a new business model, but also significantly improving existing approaches (such as existing training and health apps). The application could be further im-

proved in the future. For example, the coloring of the visualizations (especially the radar charts) could be optimized to make them easier to read. In addition, other clusters (not just the cluster to which the user was assigned) could also be used for a comparison and displayed visually. In particular, we aim to analyze recent clustering approaches that include a deep learning component (Karim et al., 2021) as compared to the conventional methods used here. Furthermore, the application could be supplemented with more detailed descriptions and explanations. The preprocessing options can also be further expanded in the future by adding additional preprocessing methods.

CODE AVAILABILITY

The code of the Streamlit application is available at <https://github.com/VaneMeyer/CustomClusterVisualizer>.

ACKNOWLEDGEMENTS

This project was funded with research funds from the Bundesinstitut für Sportwissenschaften based on a decision of Deutscher Bundestag (Project Number: ZMI4-081901/21-25).

REFERENCES

- Bishop, C. M. and Nasrabadi, N. M. (2006). *Pattern recognition and machine learning*, volume 4. Springer.
- Cao, C. (2012). Sports Data Mining Technology Used in Basketball Outcome Prediction. Master's thesis, Technological University Dublin.
- de Leeuw, A.-W., Heijboer, M., Verdonck, T., Knobbe, A., and Latré, S. (2023). Exploiting sensor data in professional road cycling: personalized data-driven approach for frequent fitness monitoring. *Data Mining and Knowledge Discovery*, 37(3):1125–1153.
- D'Urso, P., De Giovanni, L., and Vitale, V. (2022). A robust method for clustering football players with mixed attributes. *Annals of Operations Research*, pages 1–28.
- Feng, J. (2023). Designing an artificial intelligence-based sport management system using big data. *Soft Computing*, 27(21):16331–16352.
- Fister, I., Fister, D., Deb, S., Mlakar, U., Brest, J., and Fister Jr., I. (2020). Post hoc analysis of sport performance with differential evolution. *Neural Computing and Applications*, 32(15):10799–10808.
- Frevel, N., Schmidt, S. L., Beiderbeck, D., Penkert, B., and Subirana, B. (2020). Taxonomy of sportstech. *21st Century Sports: How Technologies Will Change Sports in the Digital Age*, pages 15–37.

- Goldberger, A. L., Amaral, L. A., Glass, L., Hausdorff, J. M., Ivanov, P. C., Mark, R. G., Mietus, J. E., Moody, G. B., Peng, C.-K., and Stanley, H. E. (2000). Physiobank, physiotookit, and physionet: components of a new research resource for complex physiologic signals. *circulation*, 101(23):e215–e220.
- Herberger, T. A. and Litke, C. (2021). The impact of big data and sports analytics on professional football: A systematic literature review. *Digitalization, digital transformation and sustainability in the global economy: risks and opportunities*, pages 147–171.
- Karim, M. R., Beyan, O., Zappa, A., Costa, I. G., Rebholz-Schuhmann, D., Cochez, M., and Decker, S. (2021). Deep learning-based clustering approaches for bioinformatics. *Briefings in bioinformatics*, 22(1):393–415.
- Kirchner, K., Zec, J., and Delibašić, B. (2016). Facilitating data preprocessing by a generic framework: a proposal for clustering. *Artificial Intelligence Review*, 45(3):271–297.
- Li, G. (2022). Construction of Sports Training Performance Prediction Model Based on a Generative Adversarial Deep Neural Network Algorithm. *Computational Intelligence and Neuroscience*, 2022.
- Li, X., Chen, X., Guo, L., and Rochester, C. A. (2022). Application of Big Data Analysis Techniques in Sports Training and Physical Fitness Analysis. *Hindawi Wireless Communications and Mobile Computing Volume 2022, Article ID 3741087*.
- Meyer, V., Al-Ghezi, A., and Wiese, L. (2023). Exploiting clustering for sports data analysis: A study of public and real-world datasets. In *International Workshop on Machine Learning and Data Mining for Sports Analytics*, pages 191–201. Springer.
- Narizuka, T. and Yamazaki, Y. (2019). Clustering algorithm for formations in football games. *Scientific Reports*, 9(1):1–8.
- Rendón, E., Abundez, I. M., Gutierrez, C., Zagal, S. D., Arizmendi, A., Quiroz, E. M., and Arzate, H. E. (2011). A comparison of internal and external cluster validation indexes. In *Proceedings of the 2011 American Conference, San Francisco, CA, USA*, volume 29, pages 1–10.
- Rossi, A., Da Pozzo, E., Menicagli, D., Tremolanti, C., Priami, C., Sirbu, A., Clifton, D., Martini, C., and Morelli, D. (2020a). Multilevel monitoring of activity and sleep in healthy people. *PhysioNet*.
- Rossi, A., Da Pozzo, E., Menicagli, D., Tremolanti, C., Priami, C., Sirbu, A., Clifton, D. A., Martini, C., and Morelli, D. (2020b). A public dataset of 24-h multi-levels psycho-physiological responses in young healthy adults. *Data*, 5(4):91.
- Sarlis, V., Papageorgiou, G., and Tjortjis, C. (2023). Sports analytics and text mining nba data to assess recovery from injuries and their economic impact. *Computers*, 12(12):261.
- Schmidt, S. L. (2020). *21st Century Sports*. Springer.
- Shelly, Z., Burch, R. F., Tian, W., Strawderman, L., Piroli, A., and Bichey, C. (2020). Using K-means Clustering to Create Training Groups for Elite American Football Student-athletes Based on Game Demands. *International Journal of Kinesiology and Sports Science*, 8(2):47–63.
- Thornton, H. R., Delaney, J. A., Duthie, G. M., and Dacombe, B. J. (2019). Developing athlete monitoring systems in team sports: Data analysis and visualization. *International journal of sports physiology and performance*, 14(6):698–705.
- Xu, R. and Wunsch, D. (2005). Survey of Clustering Algorithms. *IEEE Transactions on Neural Networks*, 16(3):645–678.