DETECTING OUT-OF-HOSPITAL CARDIAC ARREST USING ARTIFICIAL INTELLIGENCE

Project report

In this report of the pilot project between EENA & Corti, discover how AI can work alongside emergency call takers to improve emergency response.

Corti eena

EUROPEAN EMERGENCY NUMBER ASSOCIATION

Project report: Detecting out-of-hospital cardiac arrest using artificial intelligence

Version: 1

Publication date: 23/01/2020

Status of the document: APPROVED

Authors that contributed to this document:

Andreas Cleve, Dimitri Devillers & Matteo Palladini – Corti

Jérôme Pâris & Rose Michael – EENA

Etienne Faure – SDIS74, France

Rodolfo Bonora – AREU, Italy

EENA

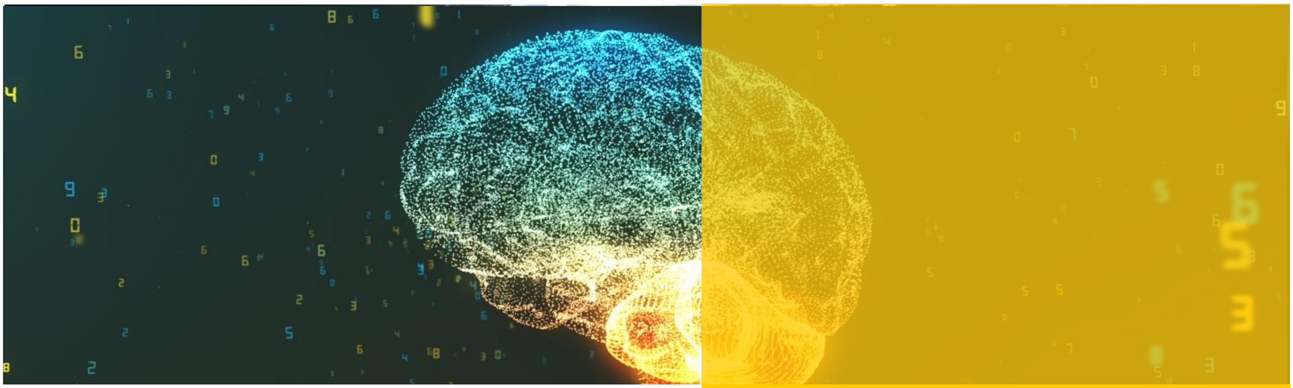
European Emergency Number Association

EENA 112

Avenue de la Toison d'Or 79, Brussels, Belgium

T: +32/2.534.97.89

E-mail: info@eena.org



1 | INTRODUCTION

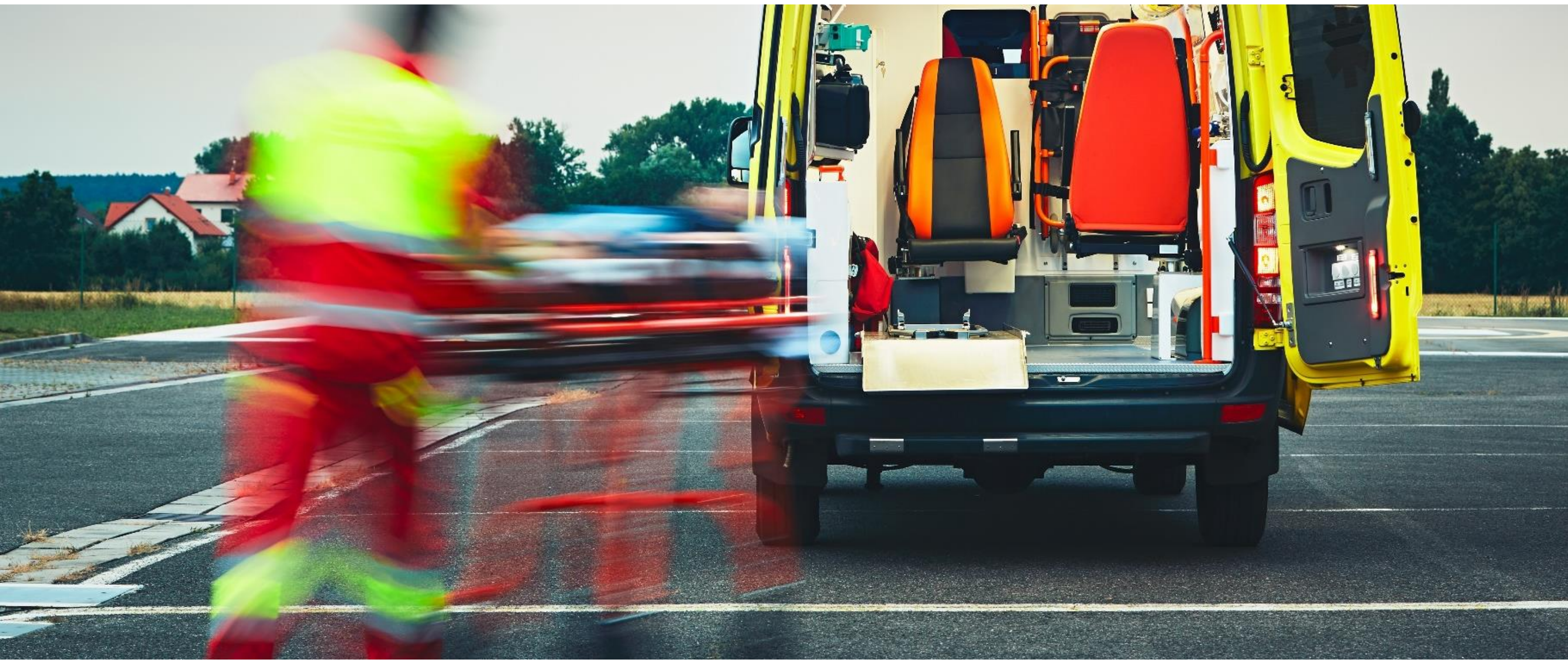
Saving time is crucial during any emergency. The quicker the response, the higher the chance of survival. This is particularly evident when someone suffers a cardiac arrest: survival dramatically decreases by approximately 10% every minute without intervention.[1] Out-of-hospital cardiac arrest is one of the leading causes of death both in Europe and worldwide. Quick and accurate decision-making by emergency call-takers is therefore crucial.

With technology industries thriving in Europe, it is important to explore how innovations can work alongside emergency response professionals. Embracing existing and emerging technologies can give new opportunities to improve emergency response and save more lives. Artificial intelligence (AI) has the potential to transform the way emergency calls are handled by providing real-time, innovative decision support to improve the quality of live detections during calls. By working alongside call handlers and dispatchers, AI could spot patterns which would be very difficult for humans and could identify cases of cardiac arrest more quickly and more accurately.

EENA and Corti partnered in 2018 and 2019 to explore how artificial intelligence could assist emergency call-takers in the detection of out-of-hospital cardiac arrest.

Corti's AI listened in on emergency calls and analysed conversations in real time in pilot sites in two different countries: France and Italy.

[1] Karch SB, Graff J, Young S, Ho CH. Response times and outcomes for cardiac arrests in Las Vegas casi-nos.Am J Emerg Med. 1998 May;16:249-53.4. and Kette F, Sbrojavacca R, Rellini G, Tosolini G, Capas-so M, Arcidiacono D, Bernardi G, Frittitta P. Epidemi-ology and survival rate of out-of-hospital cardiac arrest in north-east Italy: The F.A.C.S. study. Friuli Venezia Giulia Cardiac Arrest Cooperative Study.Resuscitation. 1998;36:153-9.



2 | PROJECT RATIONALE

EENA and Corti entered into a partnership in May 2018 for a year and a half long project to pilot AI support in emergency medical service operations. The launch of the pilot was announced at the EENA Conference 2018. The pilot consisted of running pilot sites in two different countries – France and Italy – deploying an AI product offered by Corti.

The Corti system listens in on the emergency calls and assists in the detection of out-of-hospital cardiac arrests in real time. The AI4EMS software is trained using large amounts of historical data, which would simply be unfeasible for the training of humans. The AI's insights are displayed to the dispatcher in a user-friendly manner in order to aid decision-making. The objective of the system is to make the identification of cardiac arrests quicker and more accurate, reducing the rate of human error.

During the pilot testing, the AI worked alongside emergency call handlers and assisted in detecting out-of-hospital cardiac arrests by analysing the conversations in real time. The efficacy study focused on whether Corti technology could predict out-of-hospital cardiac arrests with a performance that is at least comparable to that of human call-takers. The AI system is a support tool; it is intended as an aid to improve decision-making, not a replacement of human call-takers.

INFORMATION ABOUT EENA

EENA, the European Emergency Number Association, is a non-governmental organisation with the mission to contribute to people's safety and security. How can citizens get the best help possible if they find themselves in an emergency? This is the question we continuously try to answer.

Our vision is that every citizen can access emergency services and receive the appropriate information and care during an emergency or a disaster. To that end, we want to be the organisation in the sector driving change and making an impact.

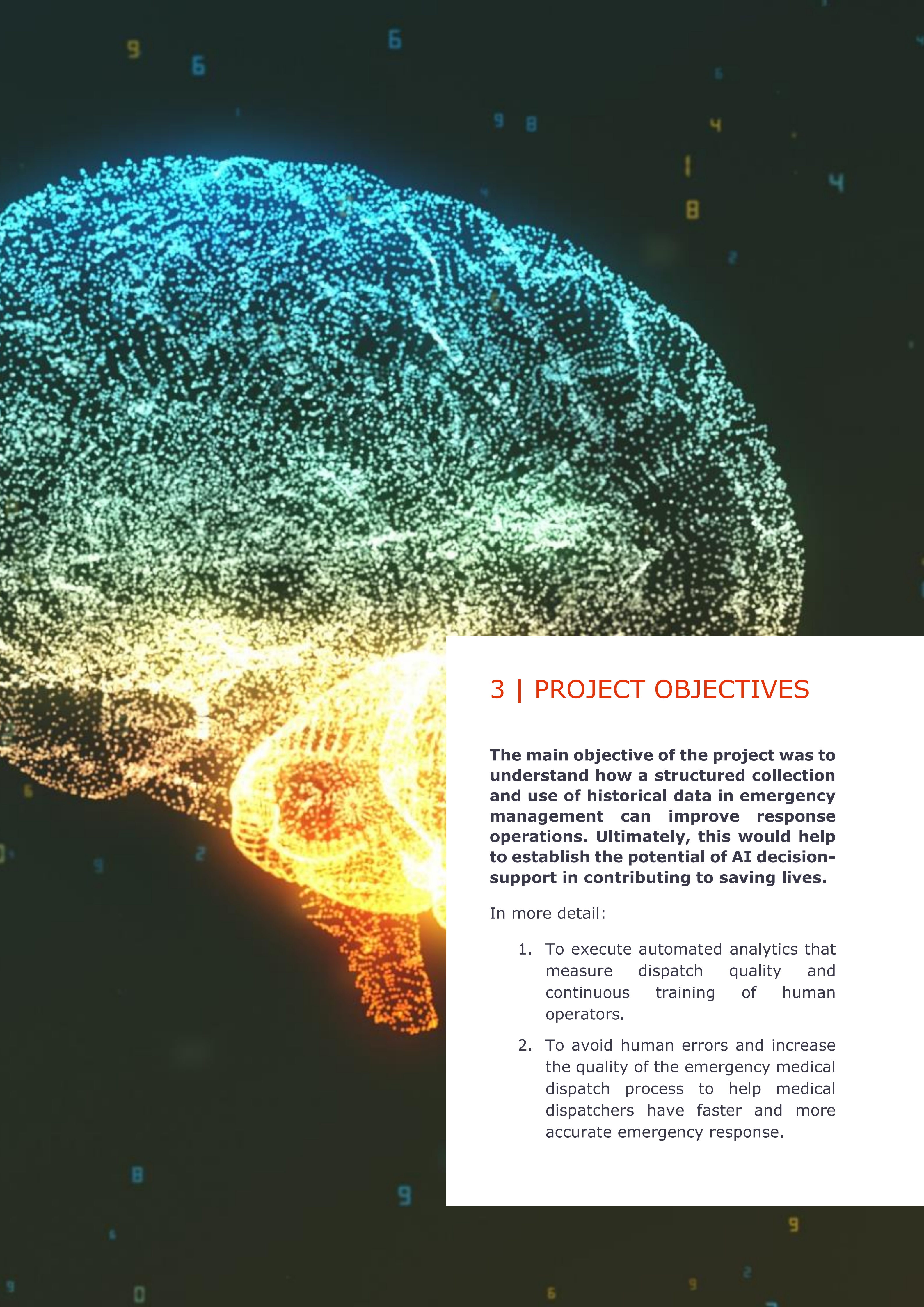
In December 2019, the EENA community includes 1500+ emergency services representatives from over 80 countries world-wide, 100+ solution providers, 100+ researchers and 200+ Members of the European Parliament. We are proud to be a platform for everyone involved in the public safety community and to provide a space for collaboration and learning.

INFORMATION ABOUT CORTI

Corti is an Artificial Intelligence (AI) company that creates AI products for Emergency Medical Services (AI4EMS). AI4EMS is based on advanced AI speech analysis deployed on top of EMS audio conversations. Corti's technology analyses live conversations and converts unstructured data into live predictions.

This powerful innovative platform aims to improve and optimise the triage and dispatch process of emergency calls involving Out-of-Hospital Cardiac Arrests (OHCA) and other critical medical conditions. Within the scope of this partnership, AI4EMS promises to deliver up to 95% accuracy at detecting OHCA (Out-of-Hospital Cardiac Arrest), reduce error rates of human call-takers and dispatchers, and make critical diagnoses faster to save lives. It lends itself to automation and offers the benefit of precise recall, positive predictive values and high-quality call transcripts to monitor dispatcher performance with unprecedented precision and depth.

AI4EMS has shown very exciting results in avoiding human errors and increasing the quality of the emergency medical dispatch process in tests so far at Copenhagen public safety answering point helping medical dispatchers make faster and more precise detections of Out-of-Hospital Cardiac Arrest.

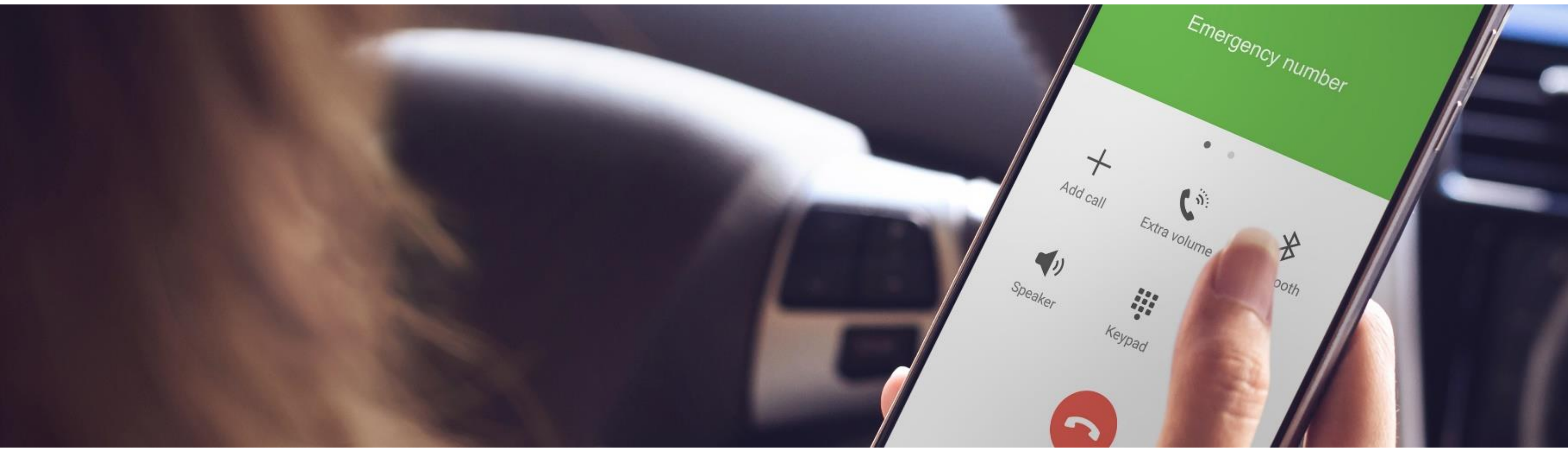


3 | PROJECT OBJECTIVES

The main objective of the project was to understand how a structured collection and use of historical data in emergency management can improve response operations. Ultimately, this would help to establish the potential of AI decision-support in contributing to saving lives.

In more detail:

1. To execute automated analytics that measure dispatch quality and continuous training of human operators.
2. To avoid human errors and increase the quality of the emergency medical dispatch process to help medical dispatchers have faster and more accurate emergency response.



4 | PILOT SITES

AREU, ITALY

AREU's mission is to manage, coordinate and monitor pre-hospital medical emergencies in Lombardy, Italy. The organisational model of AREU is: a headquarters (AREU Direction), 4 dispatch centres (SOREU), and PSAP2 and peripheral structures (AAT), which are community and territory-based, and spread around the regional area.

AAT are widespread across the territory with an area of provincial competence and responsibility for sending the appropriate means of transportation (cars and helicopters) for health emergencies after being notified by the dispatch centre (SOREU). The 4 dispatch centres (SOREU) coordinate relief operations on areas of supra-provincial competence.

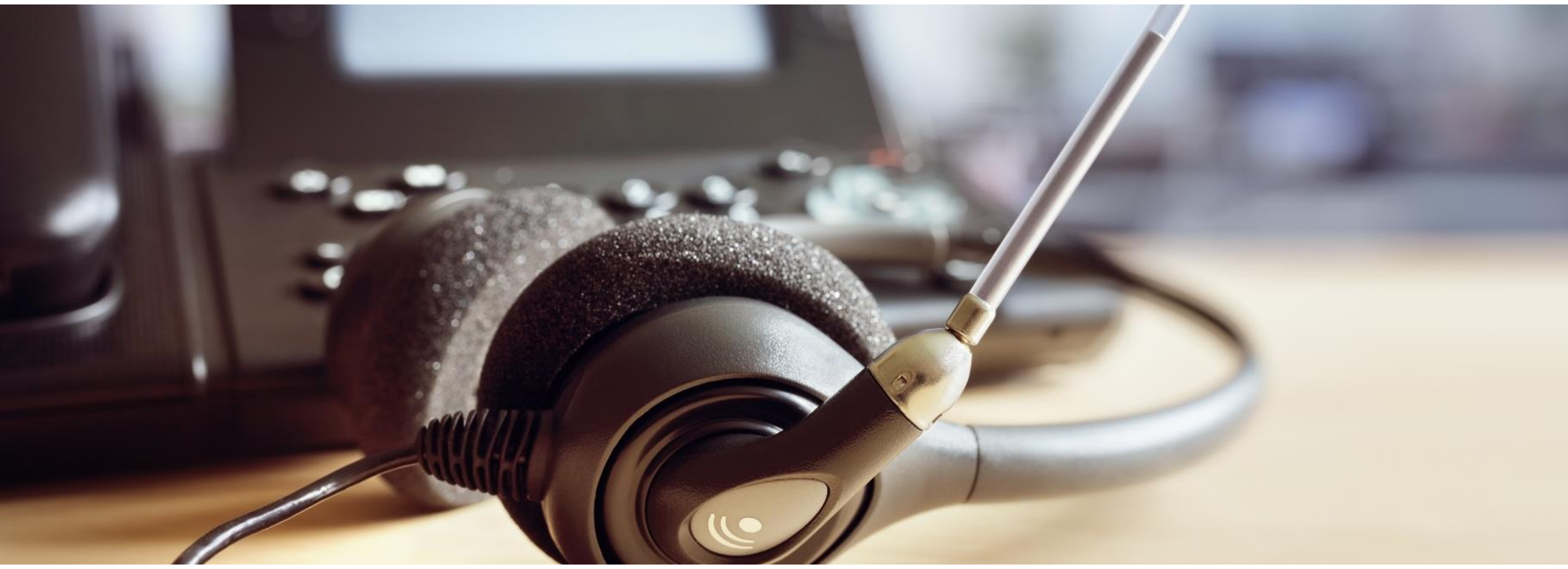
More information: *https://www.areu.lombardia.it/*

SAMU-SDIS 74, FRANCE

In France, the fire and rescue services are departmentalised and managed by the Departmental Fire and Rescue Service (SDIS). Emergency medical services are managed by SAMU.

The SAMU-SDIS 74 covers the department of Haute Savoie, an area in the Alps of Eastern France. All emergency calls – whether to emergency medical service (15), fire and rescue (18) or the European Emergency Number (112) – are dealt with in a combined call centre.

More information: *https://www.ch-annecygenevois.fr/fr*



5 | PROJECT USE CASES

After the most viable Public Safety Answering Point (PSAP) partners were found in EENA's network of European emergency services organisations, Corti collaborated with each PSAP and used historical data to build a proof of concept for that specific language.

The steps were as follows:

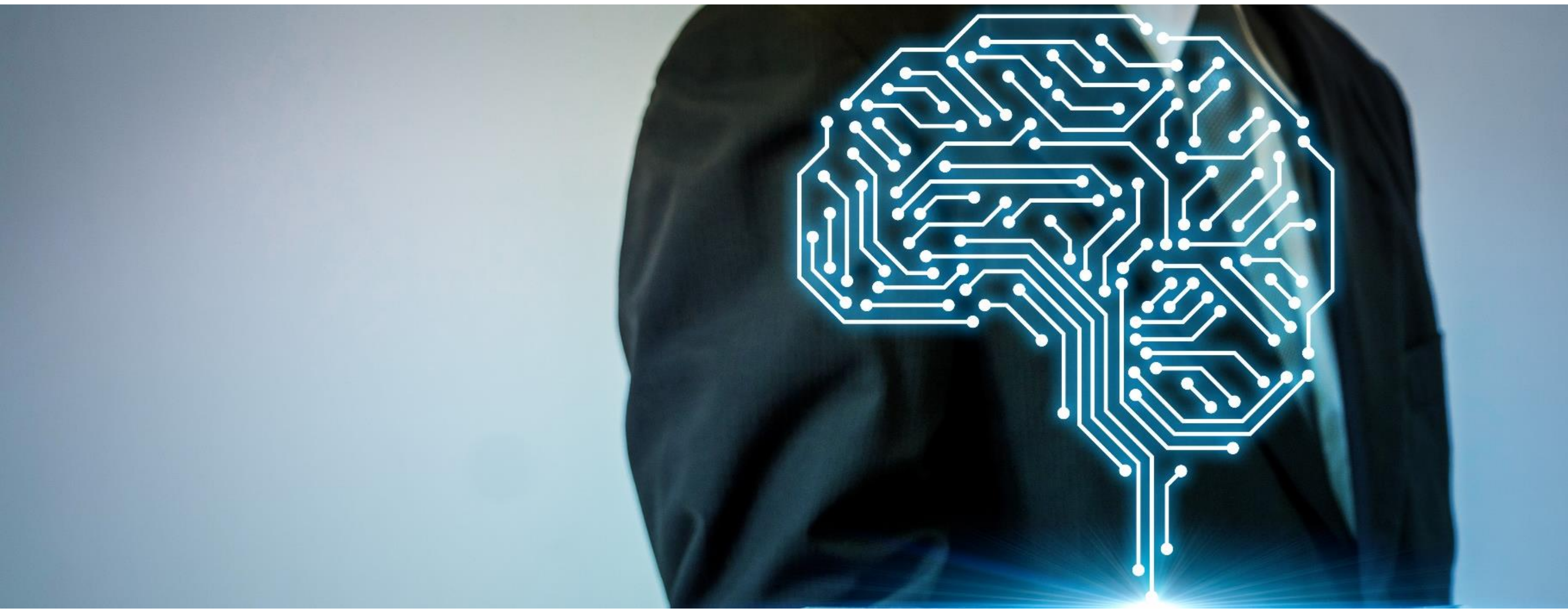
1) Language understanding

For these pilots, Corti used approximately 100 hours of historical data to build language understanding for each specific country. To do this, Corti deployed a team of data scientists to develop an initial automatic speech recognition model for each language, using Corti's proprietary language compiling technology.

2) Building a test and validation set

When a satisfactory language understanding was reached, the PSAP provided Corti with their historical data on cardiac arrests, which Corti then used to train the cardiac arrest model. When Corti could prove that the models were trained to a level where the artificial intelligence can reach the targeted accuracy, a final report and showcase was presented to the PSAPs. Finally, upon implementation, PSAPs are able to preliminary test the AI4EMS with their local personnel.

Following these steps, Corti could then begin to evaluate the impact of the AI system on the accuracy and speed of over-the-phone cardiac arrest detection.



6 | DATASETS

The Corti system is trained based on a dataset of historical emergency calls in the specific language. Each pilot site provided the dataset coupled with a few required metadata reporting specific information for each call, i.e. the presence of a cardiac arrest or its absence. This was provided through a ground-truth annotation by on-site Emergency Medical Service (EMS) personnel and call-taker annotations derived from the notes taken during this call. This allowed the results from Corti technology to be evaluated against the presence of cardiac arrest (according to the ground-truth) and the performance of the call-taker.

In the Italian pilot with AREU, the dataset consisted of 3265 emergency calls. This dataset was used to finetune the technology and evaluate the performance of Corti. Of these calls, cardiac arrest was involved in 1376 calls, according to the ground-truth annotations. The call-taker recognition variable has been built using call-takers notes as a proxy. The Corti AI system was evaluated by using the entire AREU dataset with five-fold cross-validation to predict the ground truth.

In the French pilot with SAMU-SDIS 74, the dataset consisted of 2069 emergency calls. Of these calls, cardiac arrest was involved in 1060 calls, according to the ground-truth annotations. The full dataset was used to finetune the Corti technology and the performance of the AI was evaluated on a hold-out dataset of 232 emergency medical phone calls. Out-of-hospital cardiac arrest was involved in 117 calls.

In obtaining the dataset, the General Data Protection Regulation applicable in the European Union posed significant challenges. These have been outlined in Section 7.3.

7 | OUT-OF-HOSPITAL CARDIAC ARREST DETECTION WITH AI

7.1 | PILOT RESULTS

The EENA-Corti pilot project demonstrated that AI does have the potential to provide valuable decision-support to emergency call-takers. The AI was able to detect more out-of-hospital cardiac arrests than human call-takers. The French pilot also demonstrated that Corti could also determine cardiac arrests faster, presenting a significant performance increase.

By the end of the first training at the French pilot site, Corti's technology had outmatched the capacities of the human dispatcher. With the support of the AI-powered decision support, the number of undetected out-of-hospital cardiac arrests was decreased by 5.5 percentage points.

Similarly, at the Italian pilot side, the AI system increased the number of correctly detected out-of-hospital cardiac arrests by an average of 3.9 percentage points, compared to a human call-taker.

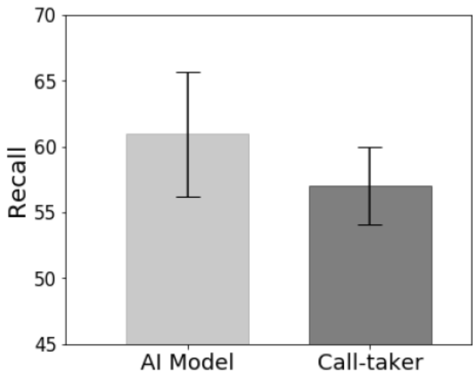


Figure 1: Recall of the AI system (left) compared to the recall of the AREU human call-takers (right). We report means and standard deviations.

The French pilot also demonstrated that the AI-powered decision support could speed up detection of out-of-hospital cardiac arrest and propose CPR. On average, the Corti technology was 2.5 times faster than the human call-taker on the more complex conversations. On average, this saves more than 2 minutes per intervention involving a cardiac arrest.

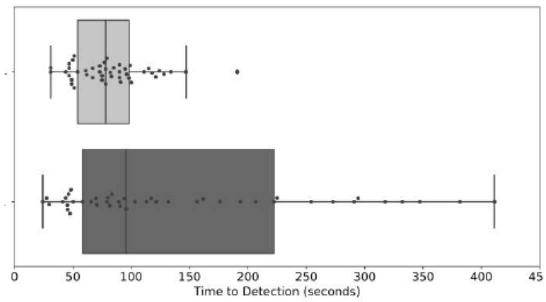


Figure 2: Top: The time to correct prediction of the AI. Bottom: The time to correct prediction of the SAMU-SDIS74 personnel.

Similarly, at the Italian pilot site, the AI system increased the number of correctly detected out-of-hospital cardiac arrests (sensitivity) by an average of 3.9 percentage points, compared to a human call-taker. Moreover, the call-takers and the AI system recorded a similar accuracy (at around 86.6%) and false-positive rates of 0.53% and 3.49% respectively. For this pilot, the AI model has been trained to achieve the highest sensitivity given an acceptable value of the false-positive rates, since in developing the AI, a conscious trade-off can be made between the sensitivity and the false-positive rate of the system.

Due to limitations in the dataset (see section 7.2 for more information), the limited size of the test set and the shorter duration of the calls when compared to the French dataset, the model's performance was lower. It was not possible to compare the time to detection between the machine learning model and the medical dispatchers, as the metadata provided by AREU did not allow such comparison.

7.2 | CHALLENGES: PRACTICAL

Datasets

Corti's AI solution trained on French and Italian datasets is already outperforming the human in its preliminary development, demonstrating promising potential with more data and training is possible. As you can see in the table below, the Corti experience so far demonstrates that model performances improve as more data and training is provided:

	Danish[2]	English[3]	French	Italian
Undetected OHCA reduction	42.3 %	19.6 %	5.5 %	3.9 %
Hours of training data	7211 h	524 h	81 h	95 h

The AI systems developed during the Italian and French pilots were trained on a limited cohort of call data. The accuracy and speed of the systems will therefore improve with time as more data is included. The limited size of the test set also imposes very strict restrictions on the model decision.

On a similar note, the metadata required for developing such machine learning models are not always available and their quality may vary depending on the data collection structure of each PSAP.

Metadata

The below list describes in more detail some of the challenges faced across the pilots concerning the metadata:

- The caller does not recognise certain symptoms such as agonal breathing or provides erroneous information.
- The call is chaotic and the call-taker has difficulty understanding what is happening.
- The ground-truth label does not accurately represent the events in the call. The labels are created at a non-specific point in time. This can range from the arrival of the EMS on-site, to after the patient is accepted in the emergency room. The cardiac arrest event could therefore have evolved after the call has happened.
- The policy for providing pre-arrival CPR instructions to by-standers might differ from one EMS to another, resulting in different level of consistency. This of course can have a significant influence on training and learning abilities of the model.
- The call-takers' adherence to triage protocols, and the actual protocols themselves, has a significant impact on how the emergency call are structured.

[2] Previous efficacy study not involved in the EENA-Corti pilot (see section 8.1).
[3] Previous efficacy study not involved in the EENA-Corti pilot (see section 8.2).

When the proexact metadata is not collected by the EMS, alternative available metadata might be used as proxy.

These points help in partially explaining the heterogeneity of the datasets leading to differences in performance between the French and Italian pilots, and generally in all preliminary developed models.

7.3 | CHALLENGES: DATA PROTECTION

In processing special categories of data, as it is data concerning health, the Emergency Medical Services figure as Data Controllers and can, therefore, benefit from the legal basis established by Article 9 of GDPR.[4]

With regard to the nature of Corti's data processing and new technology, Article 35 of the GDPR lays down a general principle applicable to any scenario where the Data Controller – once having established the existence of the use of new technologies, having taken into account the nature, scope, context, and purposes of the processing – must, prior to the processing, carry out a Data Protection Impact Assessment (DPIA). The DPIA must be carried out if the Data Controller considers that there may be a high risk to the rights and freedoms of natural persons.

The DPIA is a clear example of the so-called 'principle of accountability' and 'risk-based approach' to data protection, and it helps the Data Controller evaluate technical and organisational measures that may contribute to 'lowering' or entirely mitigating the risks of the processing. If regardless of the measures implemented, the residual risk remains high, the Data Controller should consult the local or national authority, as described by Article 36. The final decision on whether to carry out a DPIA - and consequently, to consult the national authority if deemed necessary - rest with the Data Controller's assessment and identification of the presence of a high-risk to the rights and freedoms of natural persons in the data processing.

This is the relevant European framework that has been consistently and coherently implemented across the European states the pilot sites operate in.

[4] You can consult the GDPR here: *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.119.01.0001.01.ENG&toc=OJ%3AL%3A2016%3A119%3ATOC*
EENA has also published a document on GDPR in public safety, available here: *https://eena.org/document/gdpr-public-safety/*

Besides adhering to the novelties introduced by GDPR, Corti follows strict best practices at a number of levels to ensure that all data is secure:

Access	Data is secured through FIPS-approved AES256 encryption.
	Data stored in the database is protected by multi-factor authentication with full-access audit logging.
	Data is only accessible via authorized devices located on-premise at Corti or if connected via a secure VPN tunnel.
	Individual authentication credentials are required to access data.
Redundancy	Database infrastructures and interfaces are fully redundant.
Servers	Collocation provider with ISAE 3402 Type 2 approved and ISO 27001 certified physical security. This provides full physical access control and monitoring.
Disclosure	Mutual NDA signed with every partner (and employee) to ensure data is exchanged safely during collaboration.
Transport	Data in transit is secured by Secure FTP, encrypted via SSH or HTTPS encrypted by TLS. Both are certified by FIPS.
	Data at rest is encrypted using AES256 which is certified by FIPS.
Data Processing	Depending on the deployment strategy, data is either processed exclusively on-premise or via a combination of on-premise and cloud.
Network	Data communication is protected by TLS 1.2 encryption with a non-self-signed certificate.

In Milan, Corti collaborated with AREU's legal department and Data Protection Officer (DPO) to understand how to best proceed legally according to the GDPR regulations. A Collaboration Agreement, a Data Processing Agreement, and a Non-disclosure Agreement were agreed upon and signed. Moreover, a DPIA was also carried out to describe and assess Corti's technical and organisational measures to protect the data. After evaluating the DPIA, AREU considered the risk to be relatively low and decided not to engage with the local or national authority. After the signature, the data have been safely uploaded and transferred using a secure data transfer with Virtual Private Networks (VPN).

In France, similar agreements have been signed with the SAMU of Annecy. In this case, a DPIA was not necessary and therefore was not carried out as the risk was considered low by the DPO, given the aims of the pilot project. The data have been safely shared using a USB hard disk.

7.4 | PILOTS’ EXPERIENCE AND FEEDBACK

Italy

Based on previous experiences with automatic speech recognition software which were not particularly effective, AREU approached this project with some caution. However, considering the technological improvements in the last few years, AREU was positive that they would be able to benefit and improve the performance of the dispatchers in order to have a better recognition of Out-of-Hospital Cardiac Arrests (OHCA). Indeed, the preliminary results are promising, although underlying the importance of good quality and structure in data collection.

First of all, AREU discussed and handled privacy issues, with their DPO and Corti, in accordance with the General Data Protection Regulation (GDPR). A DPIA was drafted to cautiously assess the potential risks involved for both Corti and AREU. To start the project, AREU provided over 3,000 emergency calls with metadata, about half of the calls were cases of OHCA.

For the moment, AREU’s intention is not to change the working routines of the PSAP2 dispatchers. Therefore, if the project continues to be implemented at AREU, at first Corti’s artificial intelligence models would run in the background, showing alerts to dispatcher via an API integration with AREU’s CAD provider.This is similar in principle to what is described in more detail in the section below on the French pilot.

France

The CORTI AI project has been a motivating project for all involved at SDIS – SAMU 74 and gave an insight into the future of their systems to help better rescue people. The Corti staff was very helpful and proactive in finding solutions for each challenge encountered. Particularly, the assigned project lead at Corti was key to moving the project forward during the early stages. SDIS-SAMU 74 is looking forward to going live in the production environment.

A large amount of work was carried out by Corti and the SDIS-SAMU 74 in early 2019 in order to provide over 2000 recorded calls - extracted 1 by 1 - to train the AI module:

- On French language for speech to text recognition
- On cardiac arrest detection

Along with the recorded calls, SDIS and SAMU 74 have worked on data warehouse extractions, to provide the associated metadata for each call including:

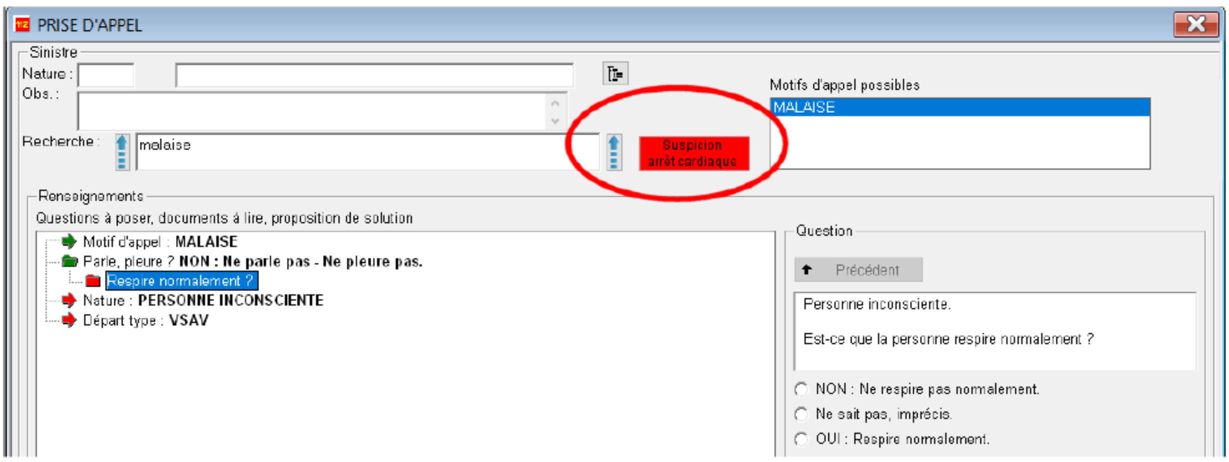
- The dispatcher’s call decision (positive / negative on cardiac arrest)
- The final diagnostic (positive / negative on cardiac arrest)

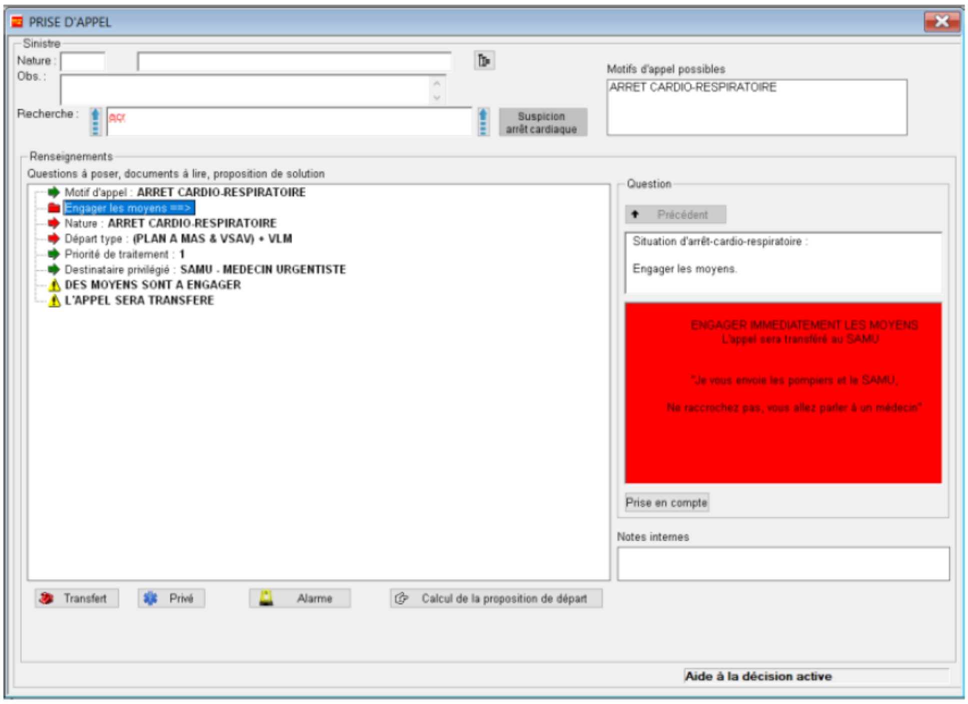
It was a challenge to build the right queries and create a reliable dataset, as the metadata is the mandatory part, with the meaning coming from the raw recorded calls.

GDPR compliance was a stumbling block in the early stages of the project for several months, until a convention was signed between Corti and SDIS–SAMU 74 to secure the data storage and ensure the end data remains at the Corti premises.

SDIS–SAMU 74 have a training environment and dedicated site since 2015. It is used for the training on the AI module within the software Start. It is part of the initial and continuous training sessions. A quick self-training tutorial video has also been released to provide on-demand training.

A built-in module has been developed jointly by SYSTEL (pilot site’s CAD supplier) and Corti, allowing the operators to keep the existing user interface “Start” call management software. This makes training very easy and AI becomes natural to use for end users handling calls, regardless of the technical complexity to achieve the end result.





The full-scale implementation of the AI module is linked to a new release of our calls and interventions management system "Start", which integrates the API with the Corti appliance. The Go-live of this latest release was successfully done at the beginning of December 2019. SAMU-SDIS 74 is now in the training sessions stage for all operators and the production go-live will be in the first quarter of 2020.

8 | PREVIOUS STUDIES

COPENHAGEN

A previous study on the efficacy of the Corti's technology ability to detect OHCA was carried out in Copenhagen. All emergency calls for all incidents responded to by the Copenhagen Emergency Medical Dispatch Centre in Copenhagen were retrieved. This dataset was used to train the machine learning framework to recognise cardiac arrest from the recorded calls.

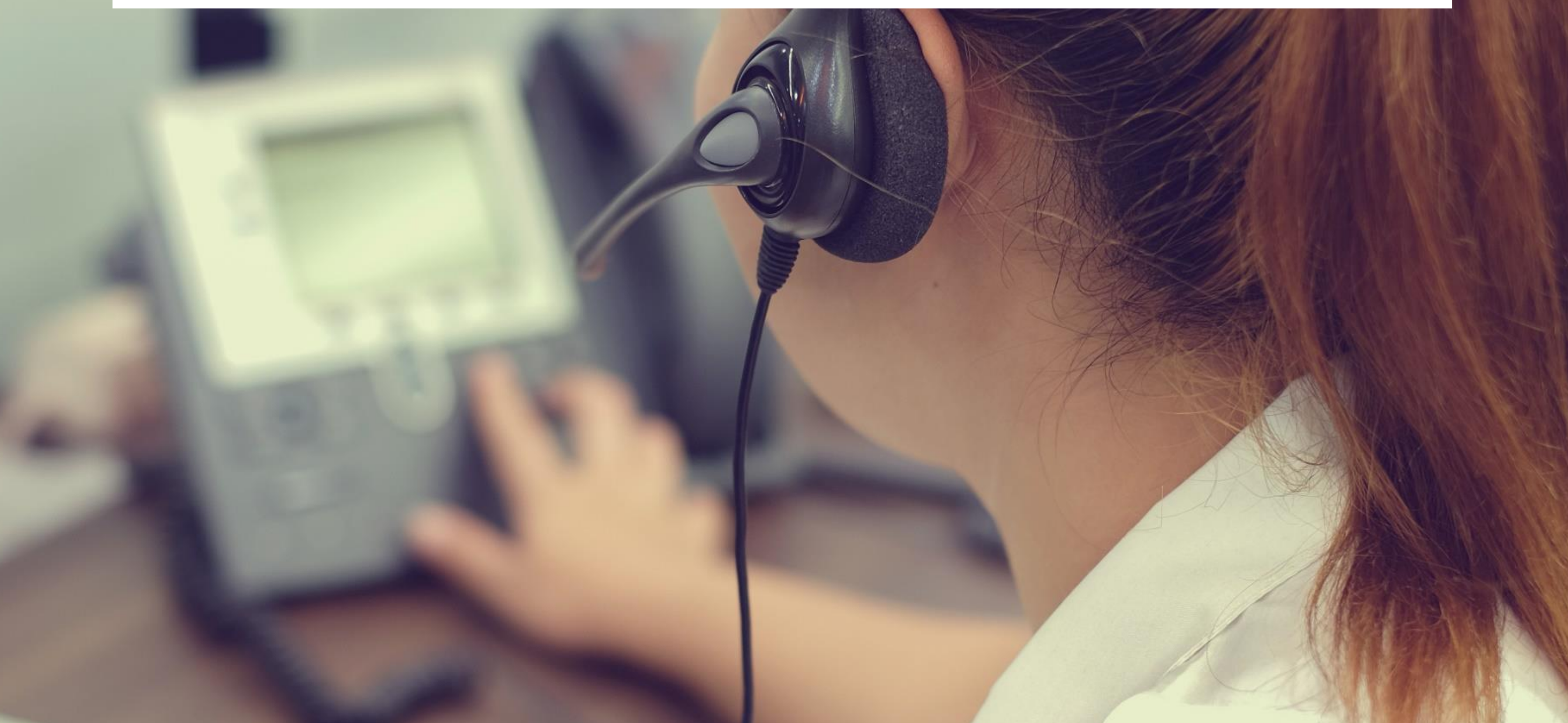
The dataset consisted of 108, 607 emergency calls, of which 918 were out-of-hospital cardiac arrests. The study concluded the AI system performed better than human call-takers in the identification of out-of-hospital cardiac arrests.

More detailed information can be found here:
https://www.resuscitationjournal.com/article/S0300-9572(18)30975-4/fulltext

SEATTLE

Another study on the efficacy on Corti's technology in detecting OHCA has been carried out in Seattle, in collaboration with the Seattle Fire Department King County (SFD).

The Seattle test dataset is comprised of audio phone calls that span a period of 189 days from August 23rd 2017 until February 27th 2018 containing mostly English speakers. Over the 189 days, SFD responded to 33,054 medical calls. Of the medical emergency calls, the final test set was of 195 OHCA (0.60%). The related scientific article is undergoing its final review round before being published in Nature magazine. It should be published in January 2020.



9 | RECOMMENDATIONS AND CONCLUSIONS

- AI does have the potential to assist decision-making of emergency call takers, by increasing the accuracy of out-of-hospital cardiac arrest detections.
- The French pilot (as well as the previous studies mentioned above) demonstrates that the AI can also speed up the detections of cardiac arrest over the phone.
- Further training of the AI is needed to keep improving the performance and optimise the models. Wider and good quality datasets play a crucial role to further improving accuracy.
- The AI should be run alongside effective protocols to ensure maximum efficacy.
- Additional data should be considered an aid to emergency call-takers and emergency response professionals in order to save lives.
- Such data should be presented in a user-friendly manner in order to be effective.