Application of Natural Language Processing (NLP) in Detecting and Preventing Suicide Ideation: A Systematic Review

Abayomi Arowosegbe [1] and Tope Oyelade [2]

1. University College London & The University of Manchester; abayomi.arowosegbe1@gmail.com
2. University College London; t.oyelade@ucl.ac.uk

* Correspondence: abayomi.arowosegbe1@gmail.com

Abstract

Introduction: Around a million people are reported to die by suicide every year, and due to the stigma associated with the nature of the death, this figure is usually assumed to be an underestimate. Suicide may be prevented if prompt intervention is taken to mitigate risk. Machine learning and artificial intelligence-based modelling, such as natural language processing (NLP) and other text analytics approaches, has the potential to become a major technique for the detection, diagnosis, and treatment of people who are suffering from mental health issues. The primary aims of this research are to determine whether NLP techniques have been utilised in the field of suicide prevention, and if so, were they effective? What were their limitations?

Methods: PubMed, EMBASE, MEDLINE, PsycInfo, and Global Health databases were searched for studies that reported use of NLP for suicide ideation or self-harm. Thematic analysis was used to synthesise and analyse the included studies. Findings were reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement, and the Mixed Methods Appraisal Tool (MMAT) was used in assessing paper quality.

Result: The preliminary search of five databases generated 387 results. Removal of duplicates resulted in 158 potentially suitable studies. Twenty papers were finally included in this review.

Discussion: Studies show that combining structured and unstructured data in NLP data modelling yielded more accurate results than utilizing either alone. Also, to reduce suicides, people with mental problems must be continuously and passively monitored. Further, NLP and other machine learning/artificial intelligence technologies can be used to address health inequities and electronic health records provide valuable data for creating suicide risk tools. Finally, Online, social media, and smartphone applications can be leverage in detecting people with suicide ideation.

Conclusion: The use of artificial intelligence and machine learning opens new avenues for considerably guiding risk prediction and advancing suicide prevention frameworks. The review's analysis of the included research revealed that the use of NLP may result in low-cost and effective alternatives to existing resource-intensive methods of suicide prevention. To summarise, there is substantial evidence that NLP is useful in identifying people who have suicide ideation.

Keywords: Natural language processing; NLP; Text mining; Suicide; Suicide-Ideation; Mental Health

Introduction

Suicide is the world's 13th leading cause of death, accounting for 5-6 percent of all fatalities (Lozano *et al*., 2012). The likelihood of completing suicide varies by sociodemographic variables around the world, with young adults, teenagers, and males bearing the largest risks (Eaton DK *et al*., 2012).

Every suicide is a tragedy that impacts families, towns, and whole nations, as well as the individuals who are left behind by the deceased. Suicide occurs at any age and was the fourth highest cause of death among 15-29 years old worldwide in 2019 (World Health Organization, 2021). Because of the COVID-19 pandemic, people all over the worldwide have been suffering from the effects of the financial crisis, mental health issues, and a sense of loneliness and isolation. These factors have heightened public awareness of the dangers of suicide. Suicidal behaviour is complicated, and no one explanation fits everyone. However, many people commit suicide on the spur of the moment, and having ready access to a means of suicide, such as poisons or weapons, may make the difference between life and death (World Health Organization, 2014). Attempting suicide by other ways, such as jumping in front of a speeding train or plunging from tall buildings, has also been reported. So, means of suicide does little or make no impact to prevent suicide.

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Suicide is a severe public health issue, but it is avoidable with early, evidence-based, and frequently low-cost measures. A robust multi - sectorial suicide prevention plan is required for national suicide interventions to be successful (World Health Organization, 2021). Innovative and cost-effective ways to collect and understand data for suicide prevention are important tools in the fight against suicide (Cook *et al.*, 2016). Approaches such as NLP combined with other machine learning techniques that utilise existing data from Electronic Medical Record (EMRs) and other repositories have the capability to improve the identification and intervention with people who have a high likelihood of attempting suicide. This is especially true given that these computational approaches can provide a low-cost alternative to other costly methods (Longhurst, Harrington and Shah, 2014).

Over the past several decades, there has been a significant expansion in the body of knowledge about suicidal behaviour. For instance, research has revealed that the interaction of biological, psychological, social, environmental, and cultural elements is an important component in influencing suicide ideation (Carson *et al.*, 2019). At the same time, the field of epidemiology has been instrumental in determining a wide variety of variables, both protective and risky, that influence the likelihood of an individual committing suicide, both in the general population and in specific susceptible groups (Cook *et al.*, 2016; Rahman *et al.*, 2022). It has also come to light that the risk of suicide varies greatly among cultures, with culture playing a role both in elevating the risk of suicidal behaviour and in providing some protection against it (Rahman *et al.*, 2022).

In terms of legislation, it is now known that 28 countries have national suicide prevention policies, and World Suicide Prevention Day, which is celebrated annually on September 10 and is coordinated by the International Association for Suicide Prevention, is recognised all over the world. In addition, a great number of research centres devoted to suicide have been established, and there are academic programmes that concentrate on the prevention of suicide (World Health Organization, 2014). Self-help groups for the bereaved have been created in several different locations, and trained volunteers are assisting with online and telephone counselling services to provide practical assistance. Non-specialized health professionals are being used to strengthen evaluation and management of suicidal behaviours. Decriminalizing suicide in many countries over the course of the last half-century has made it considerably simpler for those who struggle with suicidal tendencies to get the assistance they need (World Health Organization, 2014).

For suicide prevention strategies to be successful, there must be an improvement in surveillance and monitoring of suicide and attempts at suicide. Healthcare providers and treatment facilities need access to innovative tools that will help persons who are at risk of committing suicide get mental health care and continue to be safe until they do (World Health Organization, 2021). According to the National Institute of Health NIH, there are two primary methods for identifying who is at risk of committing suicide: first, "*Universal Screening*", which, according to some estimates, has the potential to identify more than three million adults who are at risk of committing suicide annually. The second primary method for identifying who is at risk of committing suicide is by "*Predicting Suicide Risk using Electronic Health Records*". The use of electronic medical records, including the unstructured text of patients' medical notes such as discharge summaries, is recognised as a vital resource for the provision of medical treatment as well as for medical research (NIH, 2021).

The extraction of information and the discovery of new knowledge using NLP and other machine learning methods have been successfully applied to electronic medical notes and other text data in a variety of mental health areas such as depression and post-traumatic stress disorder (PTSD). An NLP model that recognises indicators of sadness in free text, such as posts in internet forums like twitter and reddit, chat rooms, and other such sites, has been developed. Machine learning and artificial intelligence approaches were used to create this model. NLP was also used to extract emotional content from textual material to identify patients with PTSD using sentiment analysis from semi-structured interviews, a machine learning (ML) model was trained on text data from the Audio/Visual Emotion Challenge and Workshop (AVEC-19) corpus.

Suicides can be prevented, and there have been several measures and screening methods that have been taken in the past. These include limiting access to the means of suicide (such as pesticides, weapons, and certain medicines), training and education of healthcare professionals in recognising suicidal behaviour, responsible media reporting, raising awareness, and the use of mobile apps and online counselling tools, amongst other potential solutions. However, the screening tools that are now available may not be sensitive enough to enable person-centred risk detection consistently (Diniz *et al.*, 2022). Consequently, there is an urgent need for novel approaches that focus on the individual when identifying people who may be at risk for suicide. To improve upon how things are now done and to have an impact on policy, the purpose of this project is to search for, analyse, and report on additional ways suicide may be prevented using NLP and text mining approach.

Rationale

Since this is a problem that is not going away in the United Kingdom or anywhere else in the world, it is necessary that more research and studies be carried out to slow down the growing number of individuals who take their own lives.

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It is very difficult to detect suicidal ideation because people who are suicidal tend to isolate themselves and are unwilling to communicate about their thoughts (Cliffe *et al.*, 2021). As a result, detecting suicidal ideation may be extremely challenging. Those who are at risk of committing suicide need to be monitored in such a manner that it is possible to identify when they are having suicidal thoughts so that appropriate action may be taken. This will provide healthcare professional and other relevant experts the ability to save lives through timely interventions.

According to the National Institutes of Health NIH (NIH, 2021); utilising electronic medical records is one of the ways that suicide might be averted; however, there hasn't been a lot of work done in this area, especially using text analytics tools like NLP. The development of a risk stratification tool via the use of electronic medical records, including both structured and unstructured data, is one method that may be used to reduce the incidence of suicide. To contribute to the growing research landscape that could aid in the development of a suicide prevention tool, the purpose of this study is to investigate and consolidate essential work that has been done in the use of NLP for suicidal ideation.

Research Question

Can natural language processing (NLP) and other text analytics methods be used in identifying people with suicide ideation?

Aims & Objectives

Machine learning and artificial intelligence-based modelling, such as NLP and other text analytics approaches, has the potential to become a major technique for the detection, diagnosis, and treatment of people who are suffering from mental health issues (Karmen *et al.*, 2015). This was demonstrated by the emerging results of other research in mental health studies on depression, post-traumatic stress disorder (PTSD), and homelessness (Karmen *et al.*, 2015; Divita *et al.*, 2016; Levis *et al.*, 2021; Sawalha *et al.*, 2022). These studies have shown that machine learning and AI-based modelling has the potential to be an important tool. The primary aims of this research is to determine whether other approaches based on machine learning and artificial intelligence, in particular NLP, have been utilised in the field of suicide prevention, and if so, were they effective, and what were their limitations with the end goal of providing recommendations and a path forward. The objectives of this research are listed below.

- Conduct a comprehensive database search for research on the use of NLP for suicidal ideation
- Collect essential information on the detection and treatment effectiveness of the NLP approach, as well as its limitations
- Synthesize, analyse, and report findings from included studies
- Make future suggestions and identify prospective research areas
- Formulate recommendations for future efforts based on the findings of the included studies

Methodology

This was a qualitative study with the goal of completing a review of studies that had been conducted using NLP and other text analytics approaches in the identification or detection of suicidal ideation. This systematic review was carried out in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) standards to increase both the level of transparency and the quality of the reporting on publications.

Inclusion & Exclusion

All peer-reviewed journal publications published during the last 10 years will be included. Also included will be articles written or translated for publication in the English language. In addition, studies addressing the use and application of NLP methods or other text mining approaches for suicide, suicidal ideation, and self-harm in any environment, including mental health, acute, and community services, will be included.

This study will exclude research that does not include NLP or other text mining techniques. In addition, systematic reviews and other secondary sources will not be included, since only primary sources will be used for this study. All poster presentations, non-full-text submissions, and full-text submissions in languages other than English will be excluded.

Search Strategy

Using the following syntax, the Population, Phenomena of Interest, and Context (PICo) framework was used for the search approach.

((NLP OR "natural language processing" OR "text mining" OR "text analytics" OR "data mining" OR "information retrieval")

AND
("mental health" OR disorder OR depression OR suicide OR psychotic OR psychiatry OR "self-harm" OR suicidal))

Databases

A search of the relevant literature was conducted for this investigation utilising five scientific and medical databases: PubMed, MEDLINE, Embase, PsycINFO, and Global Health through the OVID platform. Several papers discovered in the reference lists of the included studies were also included.

Review Management

Mendeley was used for reference management, paper collection, and organisation. Mendeley was chosen for this study because it allows researchers to import and store papers from a variety of databases and in a variety of formats. It can also be used to remove duplicates, especially in the case of papers that appear in multiple databases, and export papers to other applications such as systematic review management systems such as Covidence and Rayyan.

Covidence was utilised to manage the systematic review. It's a web-based systematic review management software that makes it easier to create systematic reviews and other types of research reviews by screening citations and complete texts, assessing bias risk, and extracting study features and findings for analysis. The Covidence system was chosen because it speeds up the initial screening of abstracts and full texts, enabling the author and the second reviewer to collaborate on the project and resolve any disagreements about whether papers should be included or excluded.

Using Covidence, two independent researchers (AA and TO) reviewed the publications at the abstract and full-text stages in line with the inclusion criteria. Conflicts were resolved at each stage of the review until consensus was obtained. Cohen's Kappa Coefficient, which measures the degree to which the data gathered reflects the variables tested, was used to examine interrater reliability.

Quality Assessment

The quality of the included publications in this research was evaluated using the Mixed Method Appraisal Tool MMAT. The mixed-method evaluation instrument is used to evaluate quantitative, qualitative, and mixed-method studies that are included in systematic reviews of mixed-studies (Hong *et al.*, 2018). With a focus on mixed-methods research, the tool specifies a series of criteria and screening questions to obtain an overall quality score. The MMAT evaluation tool was used since it is an appropriate evaluation instrument for systematic mixed-methods reviews, i.e., reviews that comprise qualitative, quantitative, and mixed-method research. Researchers may use it to assess the methodological quality of five categories of studies: qualitative research, randomised controlled trials, nonrandomized studies, quantitative descriptive studies, and mixed methodologies research.

Data Extraction

To obtain data that was relevant from the studies that were included, a template for data extraction was designed and produced. After being exported from the systematic review management software Covidence, which was used to create the data collection template, the data were cleaned and transformed in Microsoft Word and Excel before the process of analysis could begin.
After the data had been exported into the data processing software, it was examined and investigated to determine whether the appropriate data had been collected. A matrix was then created to store the data, initial codes were derived from the data, the codes were examined, revised, and combined into themes, and finally, the themes were refined and presented in a cohesive manner.

Analysis

Thematic analysis using the reflective approach was used to construct narratives and discussions from the included papers, using codes and themes generated from the collected data. These narratives and discussions were based on the findings of the included studies. For the purposes of this research, specialised software was not required to carry out the thematic analysis. Instead, tables were created in Microsoft Word, which serve as the repository for the core themes as well as the secondary themes.
Reflective thematic analysis RFA was adopted for this research because of its widespread use and reputation as one of the more accessible methods for those with little or no prior experience in qualitative analysis (Nowell *et al.*, 2017). In addition to being widely used and suitable for unexperienced qualitative researchers and those involved in qualitative research, the identification and analysis of patterns or themes in a given data set is made easier with the help of reflective thematic analysis, a simple and theoretically flexible interpretive method to qualitative data analysis (Braun and Clarke, 2021; Byrne, 2022).

Ethics

There are no ethical issues about the safety of the participants, or the data collected in this research. Full-text literature was obtained from several medical, health informatics, and psychological sources available via the university library and other third-

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party databases. Therefore, the data and information gathered by this study are already accessible in the public and academic domains.

The lead investigators of the included studies are expected to have obtained consent from all persons, organisations, and subjects participating in their investigations. As a result, no ethical approval is required for this systematic review.

Result

Study Selection

The preliminary search, which consisted of searching five (5) separate databases with the help of the OVID platform, produced a total of 387 results. After the processing of the information in Mendeley, which is an application for reference management, a total of 158 records were produced after the deduplication process was performed.

The 158 data that had been pre-processed in Mendeley were then imported into Covidence, which is a management system for systematic reviews, and here is where the screening processing was completed. Following the review of the full text, twenty (20) studies were assessed and chosen for inclusion. The search procedure is shown in Figure 1 using the PRISMA flow diagram shown below.

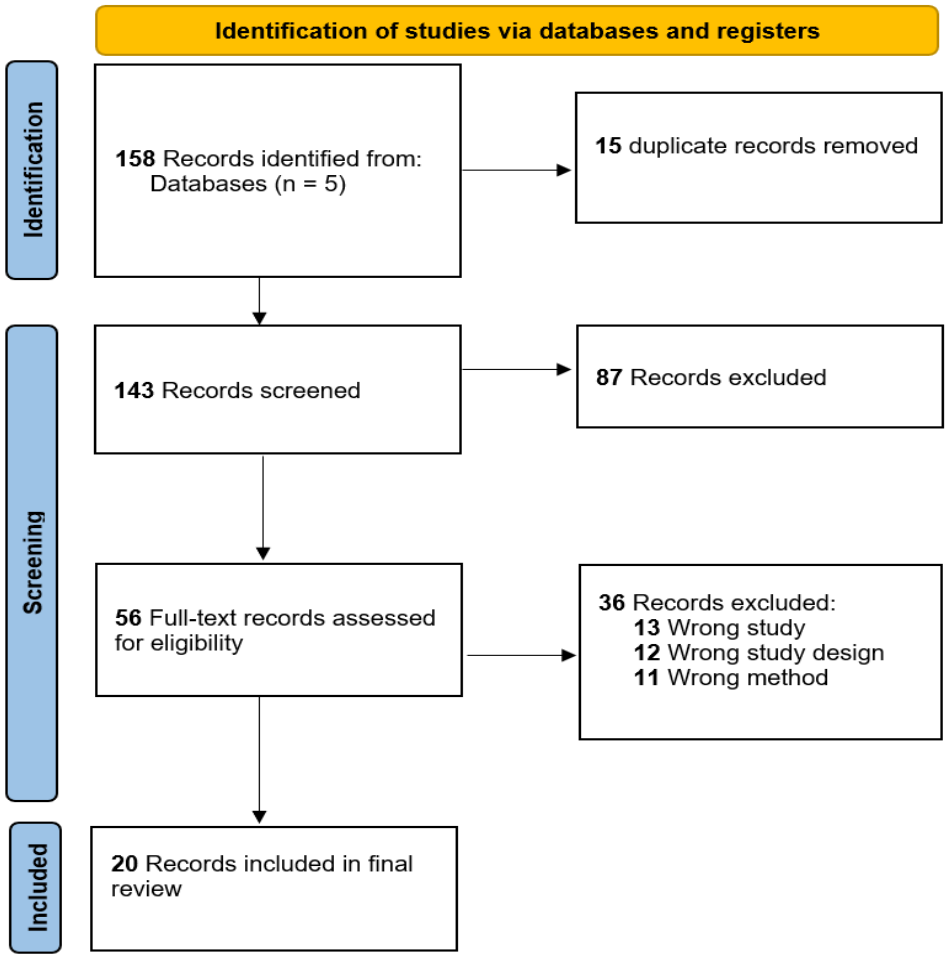

Fig 1: PRISMA Diagram

No.	Database	Number of Records
1	MEDLINE	106
2	Embase	123
3	PsycInfo	47
4	Global Health	14
5	PubMed	97
	Total	**387**

Fig 2: Database Search Result

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Study Characteristics

The characteristics of the included (n=20) studies are outlined in Table 1. Most studies (n=12, 60%) were conducted in the United States, while four studies were conducted in the United Kingdom, two in Asia, one in Spain, and one in Brazil. A total of 50% of the included studies (n=10) were done in a clinical context. 15% of the studies were conducted online or utilising mobile apps. Two studies were conducted in an emergency department setting. Studies including the modelling of EHR data (n=8), qualitative interviews (n=2), and 10 experimental studies (n=10).

Table 1: Included studies characteristics

Title	Authors	Year	Country	Aim of study	Population	Setting	Methods used	Evaluation Method	Main Findings & Results
Novel Use of Natural Language Processing (NLP) to Predict Suicidal Ideation and Psychiatric Symptoms in a Text-based Mental Health Intervention in Madrid	Benjamin L. Cook et al.	2016	Other: Spain	The study aims to use NLP and machine learning to predict suicidal ideation and heightened psychiatric symptoms among adults recently discharged from psychiatric inpatient or emergency room settings in Madrid	Adult	Participant home	Applied NLP and ML (logistic regression) approach to text messages. The intervention was delivered by text messages, sent to participants.	The model was evaluated using positive predictive value (PPV), sensitivity, and specificity on the positive cases in the remaining 50% of the sample.	It is possible to use NLP based machine learning prediction methods to predict suicide risk as well as heightened psychiatric symptoms in free-text responses sent via mobile phone. The use of novel NLP methods may create low-cost and effective alternatives to traditional resource-heavy data monitoring systems.
Improving ascertainment of suicidal ideation and suicide attempt with natural language processing	Cosmin A. Bejan et al	2022	USA	To demonstrate that NLP methods can be developed to identify suicide phenotypes in EHRs to enhance prevention efforts, predictive models, and precision medicine.	3.4 million patients, 200 million clinical notes	Clinical	Google's word2vec Word2vec trained on 10 million clinical notes from EHR extraction of seed keywords 'suicide' and 'suicidal'	A mixed method of evaluation: Manual review and compared to diagnostic codes ICD10/11, PPV, Recall, F1 score, the area under the receiver operator curve (AUROC)	NLP demonstrating consistently excellent PPV (> 95% for both outcomes) An ideal solution for ascertaining suicidal ideation and suicide attempt was provided by psychiatric forms when available in EHR
Identification of suicidal behaviour among psychiatrically hospitalized adolescents using natural language processing and machine learning of electronic health records	Nicholas J. Carson et al	2019	USA	To develop and evaluate a machine learning algorithm using natural language processing of electronic health records to identify suicidal behaviour among psychiatrically hospitalized adolescents	Adolescents 12 - 20 years	Inpatient	Unstructured clinical notes were downloaded from the year preceding the index inpatient admission. Natural language processing identified phrases from the notes associated with the suicide attempt outcome	Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy	A moderate sensitivity and negative predictive value, a modest AUC, and accuracy below the most frequent class baseline.
Use of a Natural Language Processing-based Approach to Extract Suicide Ideation and Behaviour from Clinical Notes to Support Depression Research	Palmon N et al	2021	USA	This study aimed to determine the feasibility of extracting SI from clinical notes.	3.7 million patient notes	Clinical	Data were drawn from the OM1 Real World Data Cloud (OM1, Inc, Boston, MA, USA), derived from deterministically linked, de-identified, individual-level health care claims, EHR and other data from 2013 to the present day.		Extraction of SI is feasible. Future efforts should assess the reproducibility of this approach in other data sources and examine the feasibility of classifying SI as passive or active using data contained within the clinical notes

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Using natural language processing to extract self-harm and suicidality data from a clinical sample of patients with eating disorders: a retrospective cohort study	Charlotte Cliffe et al	2021	UK	To determine risk factors for those diagnosed with eating disorders who report self-harm and suicidality	Patients diagnosed with an eating disorder in South London and Maudsley	Clinical	Analysed the data as 'event notes' in the EHRs, irrespective whether they were created during an inpatient stay, during follow-up or a telephone appointment. Individuals who received an ICD-10 diagnosis of an ED (F50.0 & F50.9) within the 12-year observation period	Manual annotations and calculating precision (PPV) and recall (sensitivity) statistics	'strong' and 'near perfect' agreement and when compared with manual annotations demonstrating the validity of the tool. This study also highlights the potential use of EHR databases to further suicidality and SH research by using NLP techniques. These tools could potentially have use with further development in risk prediction within ED services
Integration and Validation of a Natural Language Processing Machine Learning Suicide Risk Prediction Model Based on Open-Ended Interview Language in the Emergency Department	Joshua Cohen et al	2022	United States	Evaluate model performance on language from persons in a different geographic region than where the original model was developed	ED patients 18 - 65 years	Clinical - ED	37 Suicidal and 33 non-suicidal patients from two EDs were interviewed to test a previously developed suicide risk prediction NLP/ML model.	AUC of 0.81 (95% CI=0.71–0.91) and a Brier score of 0.23 when predicting suicidal risk on the 70 patient interviews collected in this study	The language-based suicide risk model performed with good discrimination when identifying the language of suicidal patients from a different part of the Us and at a later time period than when the model was originally developed and trained the study shows that integrating technology and procedures to collect language for a suicide risk prediction model into the ED workflow is feasible. A brief interview can be successfully implemented into two EDs and NLP/ML models can predict suicide risk from the patient language with good discrimination
Natural Language Processing of social media as Screening for Suicide Risk	Glen Coppersmith et al	2018	United States	The creation of an automated model for analysis and estimation of suicide risk from social media data. An examination of how this could be used to improve existing screening for suicide risk within the health care system. An exploration of the ethical and privacy concerns of creating a system for suicide risk screening not currently in care		Online	public self-stated data and using data donated through OurDataHelps.org Deep learning	10-fold cross-validation receiver operating characteristic (ROC)	These machine learning algorithms are of sufficiently high accuracy to be fruitfully used in an envisioned screening system, but the remaining parts of the system are not yet ready for implementation Although the design of an intervention system powered by algorithmic screening is technically possible, the cultural implications of implementation are far from settled
Boamente: A Natural Language Processing-Based Digital Phenotyping Tool for Smart Monitoring of Suicidal Ideation	Evandro J S Diniz et al	2022	Other: Brazil	To develop the Boamente tool, a solution that collects textual data from user's smartphones and identifies the existence of suicidal ideation		Online	An android virtual keyboard is able to passively collect user texts and send them to a web service. A web platform was developed composed of a service to receive texts from keyboard applications, a component with the DL model deployed, and an application for data visualization Twitter data, deep learning and evaluation	5-fold cross-validation	The proposed tool demonstrated an ability to identify suicidal ideation from user texts, which enabled it to be experimented with in studies with professionals and their patients. The performance evaluation results of the model selected to be deployed in the system (BERTimbau Large) were demonstrated to be promising. Therefore, the Boamente tool can be effective for identifying suicidal ideations from non-clinical texts, which enables it to be experimented with in studies with professionals and their patients

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Identifying Suicide Ideation and Suicidal Attempts in a Psychiatric Clinical Research Database using Natural Language Processing	Andrea C Fernandes et al	2018	UK	To develop NLP approaches to identify and classify suicide ideation and attempts.		Clinical	A rule-based approach to classifying the presence of suicide ideation and a hybrid machine learning and rule-based approach to identify suicide attempts in a psychiatric clinical database. Events and Correspondence document in CRIS EHR	Manually annotated gold standard set producing precision and recall statistics sensitivity of 87.8% and a precision of 91.7%	The good performance of the two classifiers in the evaluation study suggests they can be used to accurately detect mentions of suicide ideation and attempt within free-text documents in this psychiatric database. Two distinct NLP approaches are described to identify and classify suicide ideation and attempts, both of which performed well as indicated by high precision and recall statistics.
A Controlled Trial Using Natural language processing to Examine the Language of suicidal Adolescents in the emergency department	John P Pestian et al	2016	USA	To design a prospective clinical trial to test the hypothesis that machine learning methods can discriminate between the conversation of suicidal and non-suicidal individuals	Children	Clinical - ED	Semi supervised machine learning methods, the conversations of 30 suicidal adolescents and 30 matched controls were recorded and analysed. Questionnaire and interview for data gathering		The results show that the machines accurately distinguished between suicidal and non-suicidal teenagers The findings here support NLP as a strong adjunct to existing methods of determining a potentially suicidal individual
Developing a Natural Language Processing tool to identify perinatal self-harm in electronic healthcare records	Karyn Ayre et al	2021	UK	To create an NLP tool that can, with acceptable precision and recall, identify mentions of acts of perinatal self-harm within EHRs. (2) To use this tool to identify service-users who have self-harmed perinatally, based on their EHR	Perinatal - 18 years +	Clinical	NLP CRIS EHR	The evaluation was done against a manually coded reference standard Precision and recall	It is feasible to develop an NLP tool that identifies, with acceptable validity, mentions of peri-natal self-harm within EHRs, although with limitations regarding temporality
Natural language processing of clinical mental health notes may add predictive value to existing suicide risk models	Maxwell Levis et al	2020	USA	To evaluate whether natural language processing (NLP) of psychotherapy note text provides additional accuracy over and above currently used suicide prediction models.	Veterans' Health Administration VHA users diagnosed with PTSD	Clinical	EHR stored in Data Warehouse, VA users newly diagnosed with PTSD least absolute shrinkage and selection operator (LASSO)	The area under the curve (AUC) and confidence interval (95%) statistics were calculated to determine the models' predictive accuracy using the c-statistic	NLP derived variables offered small but significant predictive improvement (AUC =0.58) for patients with longer treatment duration. The small sample size limited predictive accuracy. Findings suggest leveraging NLP derived variables from psychotherapy notes offers an additional predictive value over and above the VHA's state-of-the-art structured EMR-based suicide prediction model. Replication with a larger non-PTSD specific sample is required.
Use of natural language processing in electronic medical records to identify pregnant women with suicidal behaviour: towards a solution to the complex classification problem	Qui-Yue Zhong et al	2018	USA	To develop algorithms to identify pregnant women with suicidal behaviour using information extracted from clinical notes by natural language processing (NLP) in electronic medical records	Clinical - Pregnant women	Clinical	Extracted diagnostic data from both structured codified data and unstructured clinical notes processed by NLP. The diagnostic validity of the algorithm against gold-standard labels obtained from manual chart reviews by psychiatrists and a trained researcher	gold-standard validation AUC 0.83, PPV, NPV, and sensitivity for performance validation	Showed that mining unstructured clinical notes using NLP substantially improves the detection of suicidal behaviour The addition of NLP resulted in an 11-fold increase in the number of pregnant women with suicidal behaviour

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Using natural language processing to improve suicide classification requires consideration of race	Nusrat Rahman et al	2022	USA	To improve the accuracy of classification of deaths of undetermined intent and to examine racial differences in misclassification.	10 years and older	Other	natural language processing and statistical text analysis on restricted-access case narratives of suicides, homicides, and undetermined deaths in 37 states collected from the National Violent Death Reporting System (NVDRS)	ROC curves and area under curve AUC	analysis reveals that identification of suicide among undetermined death cases with Black decedents can be greatly improved when modelled using race-specific death narratives; the rate is comparable with the prediction of suicide for White undetermined death cases There is strong evidence that NLP and automated coding methods could improve the detection of indications for suicide and might, in particular, help detection in settings where the death manner is prone to biases due to the decedent's race
Improving Prediction of Suicide and Accidental Death After Discharge From General Hospitals with Natural Language Processing	Thomas H McCoy Jr. et al	2016	USA	To determine the extent to which incorporating natural language processing of narrative discharge notes improves stratification of risk for death by suicide after medical or surgical hospital discharge	845,417 discharges	Other	Socio-demographic data, billing codes, and narrative hospital discharge notes for all patients from the hospital's EHRs. NLP / statistical analysis	AUC 0.73	Automated tools to aid clinicians in evaluating these risks may assist in identifying high-risk individuals
Natural language processing and machine learning of electronic health records for prediction of first-time suicide attempts	Fuchiang R Tsui et al	2021	USA	Aim to predict first-time suicide attempts using a large data-driven approach that applies natural language processing (NLP) and machine learning (ML) to unstructured (narrative) clinical notes and structured electronic health record (EHR) data	10 - 75 years	Clinical	Used both unstructured and structured data cTAKES NLP tool to process narrative notes	ROC and AUC	Using both structured and unstructured EHR data demonstrated accurate and robust first-time suicide attempt prediction and has the potential to be deployed across various populations and clinical settings. Using recently developed NLP analyses of unstructured textual data in EHRs provided a significant boost to the overall accuracy of these ML models
Identifying Suicidal Adolescents from Mental Health Records Using Natural Language Processing	Sumithra Velupillai et al	2019	UK	To evaluate a simple lexicon and rule-based NLP approach to identify suicidal adolescents from a large EHR databases	Adolescents	Clinical	Develop a comprehensive manually annotated EHR reference standard and assessed NLP performance at both document and patient-level on data from 200 patients CRIS EHR	PPV, recall, f1-score	Simple NLP approaches can be successfully used to identify patients who exhibit suicidal risk behaviour, and the proposed approach could be useful for other populations and settings The approach shows promising results
Screening pregnant women for suicidal behaviour in electronic medical records: diagnostic codes vs. clinical notes processed by natural language processing	Qui-Yue Zhong	2018	United States	To examine the comparative performance of structured, diagnostic codes vs. natural language processing (NLP) of unstructured text for screening suicidal behaviour among pregnant women in electronic medical records (EMRs)	Women 10 - 64 years	Clinical	NLP		The use of NLP substantially improves the sensitivity of screening suicidal behaviour in EMRs. However, the prevalence of confirmed suicidal behaviour was lower among women who did not have diagnostic codes for suicidal behaviour but screened positive by NLP. NLP should be used together with diagnostic codes for future EMR-based phenotyping studies for suicidal behaviour

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Detecting suicide risk using knowledge-aware natural language processing and counselling service data	Zhongzhi Xu et al	2021	Asia	To develop a domain knowledge-aware risk assessment (KARA) model to improve our ability of suicide detection in online counselling systems.		Online	de-identified dataset from an emotional support system established in Hong Kong, comprising 5682 Cantonese conversations between help-seekers and counsellors NLP approach	Precision, recall and c-statistic (ROC-AUC)	The proposed model outperformed standard NLP models in various experiments, demonstrating good translational value and clinical relevance The present study further confirmed that it is both possible and helpful to deploy an accurate, passive, and automatic suicide risk detection model for alerting counsellors to the presence of potential risk in a user's content during the engagement process
Comparisons of different classification algorithms while using text mining to screen psychiatric inpatients with suicidal behaviours	H Zhu et al	2020	Asia	To compare the performance of methods based on text mining screen suicidal behaviours according to the chief complaint of the psychiatric inpatients		Inpatient	The text mining method was adopted to screen suicidal behaviours. The performances of different combinations of six algorithms and two-term weighting factors were compared under various training set sizes, which were assessed by precision, recall, F1-value and accuracy SVM, KNN, CART, Logistic Regression, RF, Ada boost	Precision, recall, F1-value and accuracy	Findings provided a practical way to automatically classify patients with or without suicidal behaviours before admission to the hospital, which potentially led to considerable savings in time and human resources for the identification of high-risk patients and suicide prevention.

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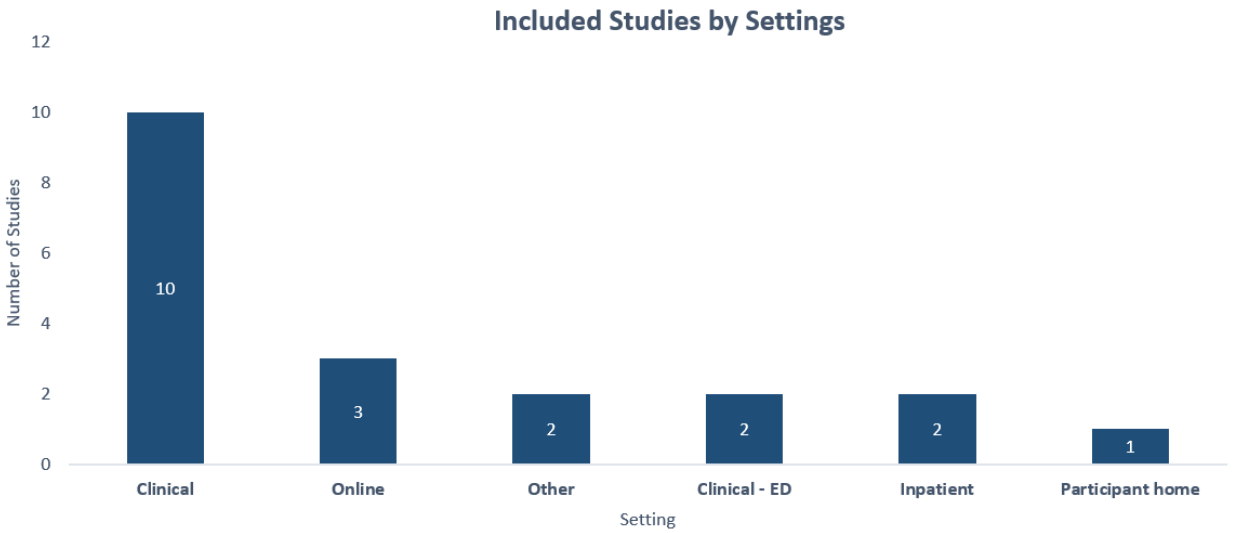

Fig 3: Studies by settings

The figure 3 above depicts the included studies by setting, with research done in a clinical context being the largest proportion (n = 10).

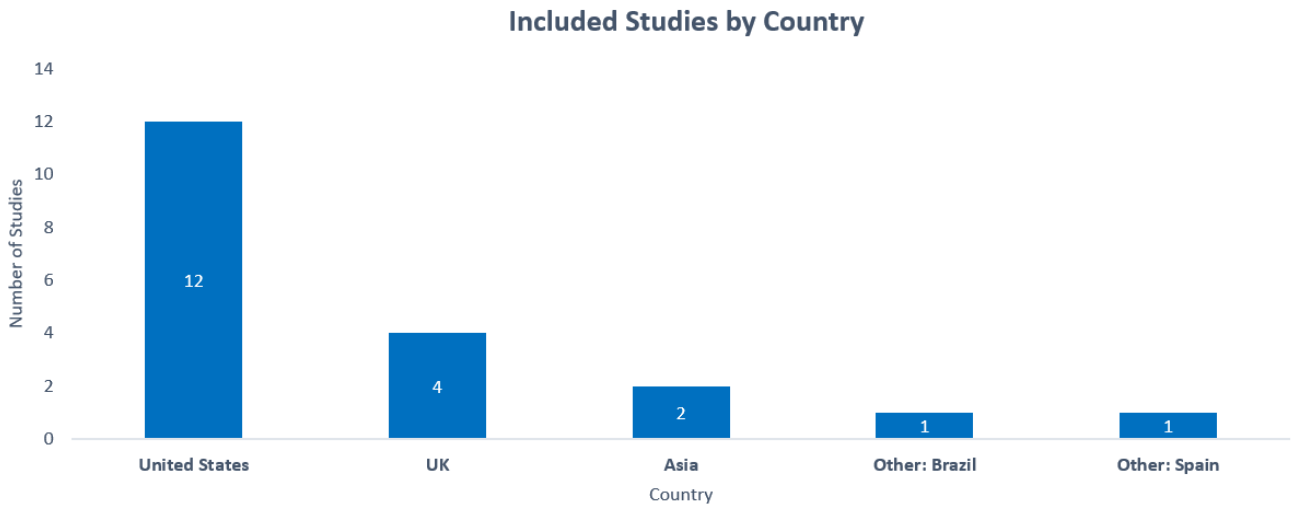

Fig 4: Studies by country

The figure 4 above depicts the breakdown of studies by country in which they were conducted, with the United States having the most (n = 12).

Screening in Emergency Departments

The unexpected nature of suicide makes it a leading cause of death, which complicates efforts being made all over the world to prevent it (Bernert *et al.*, 2020). In recent years, the ability to analyse large datasets using machine learning and artificial intelligence (ML/AI) has just been possible, which results in improved risk detection. The majority of persons who attempt suicide will travel to the nearest emergency department to obtain help (J.P. *et al.*, 2008). These individuals carry the risk of engaging in several suicide

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attempts, each one of which might end in a completed suicide. Estimating the likelihood of multiple suicide attempts is largely left to clinical judgement in the Emergency Department, where suicidal patients often appear (J.P. *et al.*, 2008). Early recognition of self-harm presentations to emergency departments (ED) may result in more prompt suicide ideation care.

In a research conducted by (Cohen *et al.*, 2022) it was investigated whether the interview approach to obtain linguistic data for the NLP/ML model might be implemented in two emergency departments in the South-eastern United States. In their research, interviews were conducted with 37 suicidal and 33 non-suicidal patients from two emergency departments to evaluate the NLP/ML suicide risk prediction model. Area under the receiver operating characteristic curve (AUC) and Brier scores were used to assess the model's performance.
The research demonstrates that it is viable to integrate technology and methods to gather linguistic data for a suicide risk prediction model into the emergency department workflow. In addition, a fast interview with patients may be used efficiently in the emergency department, and NLP/ML models can reliably predict the patient's suicide risk based on their comments.

Similar to (Cohen *et al.*, 2022), (Pestian *et al.*, 2016) created a prospective clinical trial to examine the claim that machine learning techniques may distinguish between suicidal and non-suicidal people by listening to their conversations. NLP and semi supervised machine learning techniques were used to record and evaluate the discussions of 30 suicidal teenagers and 30 matched controls using questionnaires and interviews as the data collection tools.
The findings demonstrates that the NLP model successfully differentiated between suicidal and non-suicidal teenagers.

Avoiding Perinatal Suicide

Neonatal fatalities decreased worldwide by 51%, from 5 million in 1990 to 2.5 million in 2017 (Mboya *et al.*, 2020). South Asia and sub-Saharan Africa accounted for 79 percent of the global burden of new born fatalities in 2017, although this drop has not been seen in low-income and middle-income nations, which have the largest burden of neonatal deaths (Hug *et al.*, 2019).

It has been shown that prompt delivery of high-quality healthcare services and early identification of pregnant women at risk for unfavourable maternal and perinatal outcomes throughout the prenatal period enhance mother and neonatal survival (Kuhle *et al.*, 2018). In low-resource countries where the bulk of perinatal fatalities take place at home, machine learning and artificial intelligence models may be a crucial tool in assessing risk factors for perinatal mortality and triaging pregnant women at high risk of severe postpartum outcomes.

An NLP tool developed by (Ayre *et al.*, 2021) can locate references to instances of perinatal self-harm in electronic health records with a sufficient level of recall and accuracy. Additionally, depending on their EHR, identify service users who have self-harmed during pregnancy using the NLP tool. The work demonstrates that it is possible to create an NLP tool that can recognise instances of perinatal self-harm in EHRs with acceptable validity, however there are certain temporal restrictions.

In the study by (Zhong *et al.*, 2018), researchers created algorithms that used data from clinical notes collected using NLP in electronic medical records to detect pregnant women who were exhibiting suicidal behaviour. They used both structured, codified data and unstructured, NLP-processed clinical notes to extract diagnostic information for their investigation. and evaluated the algorithm's diagnostic validity in comparison to gold-standard labels generated from manual chart checks by psychiatrists and a skilled researcher.

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The study demonstrated that using structured data and employing NLP to mine unstructured clinical notes significantly enhances the ability to identify suicidal behaviour in pregnant women. In addition, the approach led to an 11-fold increase in the number of pregnant women whose suicide behaviour was recognised.

Finally, similar to (Zhong *et al.*, 2018) research on using structured and unstructured data, (Zhong *et al.*, 2018) compares the performance of predefined diagnostic codes vs NLP of unstructured text for detecting suicidal behaviour in pregnant women's electronic health data. Utilizing NLP significantly increases the sensitivity of screening for suicidal behaviour in EHRs. Nevertheless, the proportion of verified suicidal behaviour was lower among women who did not have diagnostic codes for suicidal behaviour.

Digital Applications for Suicide Detection

Regrettably, only a small percentage of suicidal patients actively participate in their therapy, and this percentage is much lower for patients whose suicidal ideation is both frequent and strong. The good news is that while some people with a high suicide risk try to avoid face-to-face intervention, they may be more likely to try to get aid discreetly via technological means (Wilks *et al.*, 2021).

Mobile health applications (MHA) offer the potential to expand access to evidence-based care for those who have suicidal thoughts by addressing some of the constraints that are present in traditional mental health therapy (Sander *et al.*, 2021). These obstacles include stigmatisation, the perception that expert treatment is not required, and an inadequate time in an acute suicidal crisis. The proliferation of smartphones has made MHA possible. As a result, the MHA is able to deliver assistance in a timely manner, in a convenient manner, in a discrete manner, and at a cheap cost, particularly in a severe crisis since they are not constrained by time or location (Larsen, Nicholas and Christensen, 2016).

In an experimental research done by (Coppersmith *et al.*, 2018), an automated algorithm for analysing and estimating the risk of suicide based on social media data was developed. The research investigates how the technique may be used to enhance current suicide risk assessment within the health care system. It also explores the ethical and privacy considerations associated with developing a system for screening undiagnosed individuals for suicide risk.
The research indicates that the technology can currently be used for intervention with people who have decided to opt in for the intervention service. However, the technology allows scalable screening for suicide risk, with the possibility to identify many people who are at risk prior to their engagement with a health care system. Moreover, even though the development of the intervention system based on algorithmic screening is technologically possible, the cultural ramifications of its implementation are not yet decided.

(Diniz *et al.*, 2022) developed the Boamente program, which gathers textual data from users' smartphones and detects the presence of suicidal ideation. They created an Android virtual keyboard that can passively gather user messages and transfer them to a web service using NLP and Deep Learning. They then created a web platform that included a service for receiving text from keyboard apps, a component with the deep learning model implemented, and a data visualisation application.
The technology exhibited the capacity to detect suicidal thoughts from user messages, nonclinical texts, and data from third-party social media apps such as Twitter, allowing it to be tested in trials with professionals and their patients.

Similar to (Diniz *et al.*, 2022), (Cook *et al.*, 2016) employ NLP and machine learning to predict suicide ideation and elevated mental symptoms among adults (18+) recently released from psychiatric inpatient or emergency hospital settings in Spain. They used NLP and ML (logistic regression) on participant-sent text messages. The text message included a link to a questionnaire and a mobile application for collecting participant replies. The research demonstrates that it is feasible to apply NLP-based machine learning predictions algorithms to predict suicide risk and elevated mental symptoms from free-text mobile phone answers.

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A domain Knowledge Aware Risk Assessment (KARA) model is created in an experimental research by (Xu *et al.*, 2021) to enhance the capability of suicide identification in online counselling systems. In their research, they used NLP on a de-identified dataset of 5,682 Cantonese talks between help-seekers and counsellors from a Hong Kong emotional support system.
According to their research, it is both feasible and beneficial to utilise an accurate, passive, and automated suicide risk detection model to inform counsellors of potential risks in a user's information while they are engaging with the user. Additionally, the NLP model performed better than traditional NLP models in several experiments, indicating strong clinical relevance and translational utility.

Suicide Prevention using Electronic Health Records EHR

According to research, electronic health record (EHR) data, in addition to clinical decision support system (CDSS), may act as a "early warning system" to notify professionals about patients who should be evaluated for suicide risk (Lu *et al.*, 2009; Warrer *et al.*, 2012).
A CDSS is a health information system that may be incorporated into EHR system or healthcare workflow, allowing clinicians to utilise it easily and effectively. Because of its capacity to deliver evidence-based healthcare to the point of treatment, the usage of these technologies has increased in recent years (Berrouiguet *et al.*, 2009).

In these four studies (Carson *et al.*, 2019; Cliffe *et al.*, 2021; Palmon *et al.*, 2021; Bejan *et al.*, 2022), NLP was used on clinical notes obtained from electronic health records (EHR), such as the Clinical Record Interactive Search (CRIS) system, in order to identify patients who are at risk of suicidal ideation. Using NLP approaches, these investigations demonstrated the potential application of EHR information to further research on suicidality and self-harm. According to the findings of their studies, these technologies also have the potential to be useful in the expansion of risk prediction in several other areas of mental health such as eating disorder and depression.

In addition to utilising clinical notes extracted from EHR, McCoy and colleagues (McCoy *et al.*, 2016) used sociodemographic data, billing codes, and narrative hospital discharge notes for each patient taken from the electronic health records (EHRs) of the hospital in order to enhance suicide risk prediction. The research demonstrates that utilising textual data other than clinical notes, such as demographic, diagnostic code, and billing data, might help clinicians in assessing suicide risks and may help in identifying high-risk people with high precision.

Using psychotherapy and psychiatric data from EHRs might potentially enhance suicide risk prediction as shown in these two studies. (Zhu *et al.*, 2020; Levis *et al.*, 2021) extracted EHR data of hospitalised patients and PTSD patients. And applied NLP, SVM, KNN, CART, Logistic Regression, RF, Adaboost, and LASSO for a suicide risk prediction tool. The results imply utilising NLP and data from psychotherapy and psychiatric notes to automatically categorise patients with or without suicide ideation before hospitalisation, could possibly result in significant time and resource savings for the identification of high-risk patients and the prevention of suicide.

Racial Disparity

Suicide prevention initiatives must be more carefully targeted if they are to be successful. Racial and ethnic disparities in rates of suicidal thoughts, suicide attempts, and suicide fatalities must be understood (Suicide Prevention Resource Center, 2020). The likelihood of suicide varies across racial and ethnic groups depending on their experiences with prejudice, past trauma, and availability to culturally appropriate mental health care. At the same time, under reporting and other shortcomings in data collection methods restrict the understanding of racial and ethnic disparities in suicide and suicidal behaviours (Kessler, Borges and Walters, 1999; Perez-Rodriguez *et al.*, 2008).

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Studies have repeatedly shown that young people and women are more likely to engage in suicide behaviours (Hopkins *et al.*, 2018). The connection between race, ethnicity, and suicide ideation, on the other hand, is far less well understood. (Rahman *et al.*, 2022) undertook a study to enhance the accuracy of the categorization of undetermined-intent fatalities and to evaluate racial disparities in misclassification. National Violent Death Reporting System (NVDRS) restricted-access case narratives of suicides, murders, and undetermined deaths in 37 states were subjected to NLP and statistical text analysis.
Their analysis demonstrates that the identification of suicide in deaths involving black decedents can be significantly improved by employing race-specific death narratives in modelling; in their experiment employing race-specific narratives, the suicide prediction rate was comparable to that for unexplained deaths involving White decedents. In addition, there is strong evidence that NLP and automated coding systems might improve the detection of suicide warning signals, which could be especially valuable in situations where the way of death is sensitive to racial bias.

Quality Assessment

After an MMAT evaluation, the studies that were included were found to be satisfactory. On the other hand, some studies included a very limited description of the methodology, population, and settings at which their study was carried out.

Discussions

This is the first qualitative systematic review on the use of NLP for suicide prevention. Using both structured and unstructured data in data modelling with NLP yielded much more accurate results, as compared to using either structured or unstructured data alone. Multiple studies demonstrate that integrating structured data, such as diagnosis code, demographics, and billing data, with unstructured data, such as narratives, increases the performance and accuracy of detecting individuals with suicidal ideation.

Also, persistent, and passive observation of individuals with a confirmed diagnosis of mental health issues is essential and has been shown to reduce suicide and self-harm incidence (Xu *et al.*, 2021; Diniz *et al.*, 2022). It has been reported previously that up to ninety percent of suicides are associated with mental health issues (Brådvik, 2018), therefore passively monitoring persons with a confirmed diagnosis using an NLP or other ML/AI-based suicide risk assessment tool might be useful and advantageous. However, ethical and privacy problems should be examined regarding the use of patient data for suicide surveillance or monitoring, and additional research is necessary to impact government policy in this area.

In addition, EHRs of ethnic minority patients have been reported previously to include less notes and details than those of non-ethnic patients (Kessler, Borges and Walters, 1999). Data equality is vital for reducing and preventing suicidal ideation, maximising the potential of NLP and other machine learning and artificial intelligence technologies, addressing health disparities, and ensuring fair access to services. Further, the use of race-specific data in the development of suicide risk or prediction systems might boost accuracy and performance while avoiding racial bias. Occasionally, researchers and developers ignore this kind of information, which has been found to improve the effectiveness of prediction tools (Rahman *et al.*, 2022).

Electronic health records have a variety of information, which is crucial for building a suicide risk assessment tool. In addition to EHR, it is also feasible to utilise the social media, and smartphone applications data to detect individuals with suicidal ideation. Sometimes, to escape the societal stigma associated with suicide thoughts, people may use online platforms such as blogs, tweets, and forums to express themselves (Larsen, Nicholas and Christensen, 2016; Sander *et al.*, 2021). Indeed, including smartphones and social data in NLP models may enhance suicide diagnosis.

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This research confirms the results of a previous study (Le Glaz *et al.*, 2021), that NLP can be used in detecting and treating mental health issues including suicide and self-harm. In addition, NLP techniques may provide insights from unexplored data such as those from social media and wearable devices that are often inaccessible to care providers and physicians. Indeed, while machine learning and artificial intelligence solutions are not intended to replace clinicians in the prevention of suicide or other mental health issues, they can be used as a supplement in all phases of mental health care, including diagnosis, prognosis, treatment efficacy, and monitoring.

Limitations

This study has some limitations. Firstly, preprint and unpublished paper were not included in this study. Thus, grey studies and other data may exist which are not covered herein. However, Ovid-based databases including MEDLINE and Embase were systematically searched and retrieved studies were subjected to manual reference search.

Secondly, the methodologies utilised in the included research are too heterogeneous, and there are no metrics available to assess their efficacy. As a result, meta-analysis could not be conducted.

Lastly, the efficacy of NLP in preventing suicide ideation and self-harm could not be quantified as the included studies did not provide any metrics to the effect. Future study should give this a high priority since it might provide additional information regarding the efficacy of NLP in mental health.

Conclusion

According to the findings of this research work, NLP could help in the early detection of individuals who have suicidal ideation and allow timely implementation of preventive measures. It is also found that passive surveillance via mobile applications, online activity, and social media may help in the early diagnosis and prevention of suicide in vulnerable groups. However, before passive surveillance can be clinically useful, ethical and security issues need to be addressed.

When modelling, employing race specific terminologies has been demonstrated to boost both performance and accuracy among ethnic minority groups. This may boost health equality and allow equitable access to healthcare services. Furthermore, combining structured and unstructured data have been reported to enhance accuracy and precision in suicide detection, which is important for developing an NLP model for predicting suicide risk.

In summary, the application of artificial intelligence and machine learning offers new prospects to significantly enhance risk prediction and suicide prevention frameworks. Based on included studies, the use of NLP may be used to develop low-cost, resource-efficient alternatives to conventional suicide prevention measures. Thus, there is significant evidence that NLP is beneficial for recognising individuals with suicidal ideation, consequently giving unique opportunities for suicide prevention.

Recommendations

Based on the results that were obtained from this review, the following recommendations have been made:

- Reducing suicide is a collective effort; the government should form a suicide prevention task group under DHSC to explore technical solutions for early suicide detection

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- Since most people with suicide ideation seek help from ED first, integrating NLP-based CDSS in ED workflow for suicide risk might help identify them early
- Adequate training should be giving to staff to recognise unconscious racial bias when using EHR systems to record patients' data
- Including race-specific data in EHR systems and utilising them as a standard for developing suicide risk prediction tools
- More study is required to explore privacy issue, and ethics of passive data surveillance or monitoring, particularly on those with mental illness

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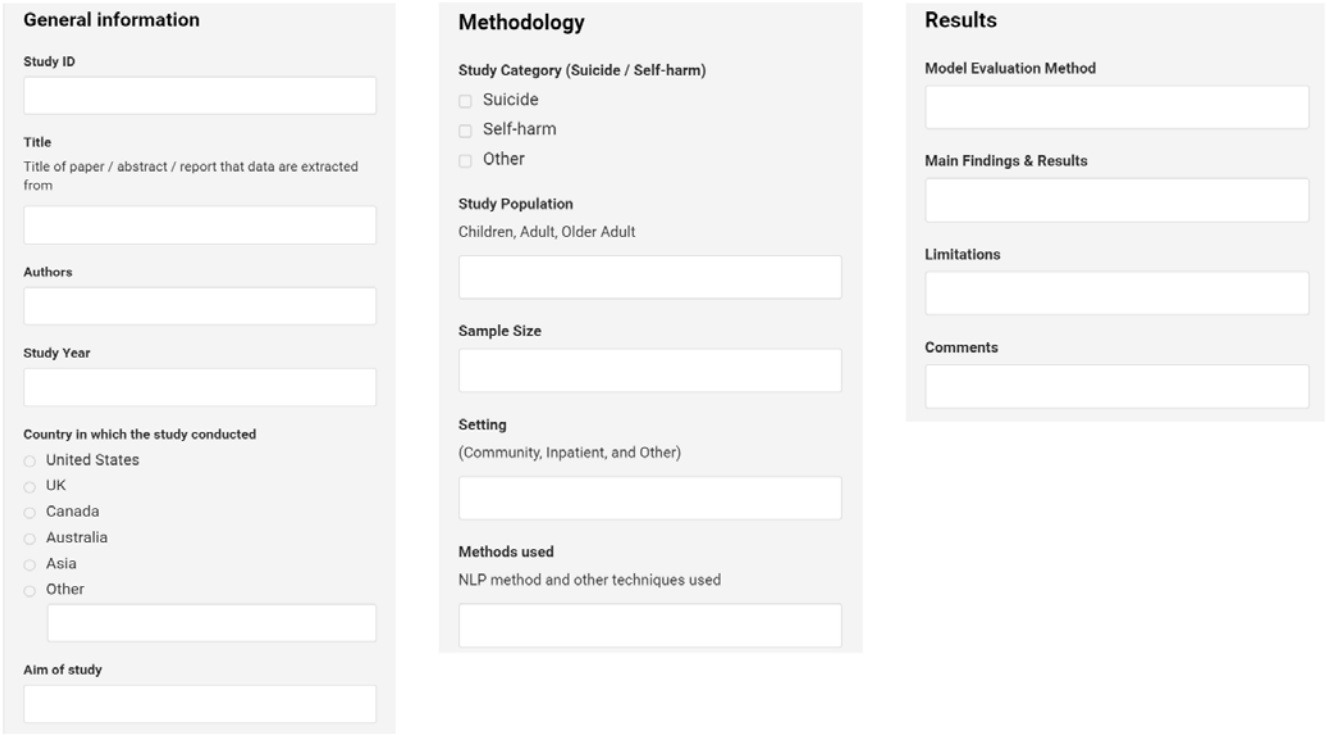
Appendices

Appendix 1: Data Extraction Form



General information

Study ID

Title

Title of paper / abstract / report that data are extracted from

Authors

Study Year

Country in which the study conducted

- United States
- UK
- Canada
- Australia
- Asia
- Other

Aim of study

Methodology

Study Category (Suicide / Self-harm)

- Suicide
- Self-harm
- Other

Study Population

Children, Adult, Older Adult

Sample Size

Setting

(Community, Inpatient, and Other)

Methods used

NLP method and other techniques used

Results

Model Evaluation Method

Main Findings & Results

Limitations

Comments

Appendix 2: Mixed Methods Appraisal Tool

Authors	SQ1	SQ2	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	5.1	5.2	5.3	5.4	5.5
Benjamin L. Cook et al.	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	CT	Yes	na	na	na	na	na
Cosmin A. Bejan et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes
Nicholas J.Carson et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na
Palmon N et al	Yes	CT	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	No	Yes	Yes	na	na	na	na	na
Charlotte Cliffe et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na
Joshua Cohen et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na	na	na	na	na	na
Glen Coppersmith et al	Yes	CT	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na	na	na	na	na	na
Evandro J S Diniz et al	CT	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	No	Yes	Yes	na	na	na	na	na	na	na	na	na	na
Andrea C Fernandes et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na
John P Pestian et al	Yes	Yes	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Karyn Ayre et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na	na	na	na	na	na
Maxwell Levis et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na
Qui-Yue Zhong et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	No	No	na	na	na	na	na	na	na	na	na	na
Nusrat Rahman et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	No	na	na	na	na	na	na	na	na	na	na
Thomas H McCoy Jr. et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	CT	na	na	na	na	na
Fuchiang R Tsui et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na	na	na	na	na	na
Sumithra Velupillai et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na
Qui-Yue Zhong	Yes	Yes	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Yes	Yes	CT	CT	Yes	na	na	na	na	na
Zhongzhi Xu et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na	na	na	na	na	na
H Zhu et al	Yes	Yes	na	na	na	na	na	na	na	na	na	na	Yes	Yes	Yes	Yes	Yes	na	na	na	na	na	na	na	na	na	na