Chapter 1

Introduction

1.1 Motivation

The complex and interconnected nature of human and mental health often manifests in the diverse ways in which speech and language disorders overlap. These disorders, affecting fundamental factors of communication, can arise within neurological and psychiatric conditions (Benedetti et al., 2006). Neurological disorders such as Parkinson's Disease (PD) and Alzheimer's Disease (AD) involve degeneration/damage of the nervous system, including the brain and nerves. In contrast, psychiatric disorders are characterized by behavioral and emotional disruptions (Nussbaum and Ellis, 2003).

On the one hand, Major Depressive Disorder (MDD) is a prevalent mental health condition affecting millions of people globally. In European region countries, the prevalence of depressive disorders was approximately 4.5% in 2016, affecting around 21 million people (OECD and European Union, 2018). MDD is characterized by persisting feelings of sadness, notable changes in appetite, sleep disruptions, cognitive impairments affecting concentration and memory, intense feelings of worthlessness or guilt, and in severe cases, suicidal thoughts or self-harm, requiring immediate intervention and support (Rush et al., 2000).

On the other hand, neurodegenerative diseases can occasionally disrupt the communication between neurons. When this occurs, it can result in issues

related to behavior, motor function, memory, and mood – essentially the same problems that psychiatrists address (Nussbaum and Ellis, 2003). This correlation is not unexpected and aligns since many scientists believe impaired neural communication in the brain is at the core of psychiatric disorders, including conditions such as depression (Kanner, 2004).

Furthermore, the relationship between these disorders is characterized by overlapping symptoms, shared risk factors, and common neural pathways. While these disorders are distinct in many ways, recognizing their interplay is important for accurate diagnosis and effective treatment. The decision to refer a patient to a psychiatrist or neurologist can be challenging for primary care providers, especially when dealing with symptoms such as fatigue, mood changes, or memory issues. Additional anamnesis and physical examination are often necessary to determine the most suitable direction.

However, the variable response to treatment has raised questions about the accuracy of the "depression" assessment, suggesting that depression may be a common feature among various conditions (e.g., neurological disorders) with different underlying causes (Benedetti et al., 2006; Kanner, 2004). Even though accurate diagnosis of depression is crucial for effective treatment, it remains challenging. Objective measurement and tracking of depression often require indirect assessments.

The integration of speech and Natural Language Processing (NLP) technologies holds significant promise in assessing, diagnosing, and monitoring neurodegenerative and emotional disorders. These technologies may enhance our understanding of these conditions, facilitate early detection, and improve the overall quality of care provided to affected individuals. This thesis works towards improving the understanding and performance of assessing different factors associated with neurodegenerative (AD and PD) and emotional disorders (depression). Additionally, it focuses on the automatic evaluation of speech and language technologies in assessing and monitoring these conditions, considering the interconnection and overlapping symptoms of both disorders from a speech and language processing perspective.

1.2 Psychiatric/Neurological Disorders in Selected Populations

1.2.1 Major Depression Disorder

Speech and Language production

Monitoring depression is essential for assessing treatment effectiveness, detecting early signs of depression, preventing relapse, and ensuring patient safety, especially in severe cases. Clinicians frequently rely on subjective observations of speech patterns to assess symptom severity, noting reduced verbal activity, shorter utterances, slower speech rate, and increased pauses in speech affected by depression (Cummins et al., 2015; Low et al., 2020).

Depression can also lead to speech changes, including monotonicity, slurred speech, devoicing, hoarseness, and reduced volume. While these changes may vary among individuals and not always be obvious or severe, they can offer valuable insights into the emotional state (Cummins et al., 2015).

In terms of prosodic features, fundamental frequency (F0) and energy contours are often used to investigate depression. In addition, the patients exhibit limited pitch range, slower speech, and articulation errors (Darby and Hollien, 1977; Hollien, 1980; Trevino et al., 2011). However, findings on the relationship between reduced F0 range and average F0 with increasing depression severity have been inconsistent. This variability may be attributed to the diversity of depression symptoms, gender differences, and variations in F0 extraction techniques (Hönig et al., 2014; Mundt et al., 2007; Quatieri and Malyska, 2012; Yang et al., 2012). Several studies have indicated that depressed patients tend to speak at a slower rate compared to Healthy Controls (HC). This reduction in speech rate remains a subject of debate, with some suggesting it reflects motor impairment, while others propose it signifies lowered cognitive functioning related to motivation (Alghowinem et al., 2012; Hönig et al., 2014). Additionally, related to acoustics, certain voice quality features, such as shimmer and spectral harmonic, have shown strong negative correlations with depression

severity, implying a breathier phonation in depressed speech. This aligns with the hypothesis that motor retardation in depression reduces laryngeal muscle tension, resulting in a more open glottis, which generates turbulent airflow. Glottal spectrum analysis has also revealed intriguing findings, suggesting that irregularly shaped glottal pulses due to increased laryngeal tension may contribute to higher energy in the upper-frequency bands of the glottal spectrum in depressed patients (Cummins et al., 2015; Low et al., 2020).

Language in depression often reflects the emotional and cognitive impact of the condition. Common features of language in individuals with depression include an increased use of negative and pessimistic language, self-criticism, a reduced vocabulary, expressions of uncertainty, social withdrawal resulting in fewer and less complex conversations, rumination on negative thoughts, reduced speech, and a lack of emotional expressiveness (Bucci and Freedman, 1981). Among the common linguistic patterns, depression patients tend to increase the use of first-person singular pronouns, potentially linked to their self-focus. These language characteristics can vary in severity among individuals and can serve as important indicators of a person's emotional state (DeSouza et al., 2021).

Clinical diagnosis

Assessing an individual's emotional state and behavior for diagnosing depression frequently relies on standardized criteria, such as the Fifth Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (Edition et al., 1994). This diagnostic process also involves a range of assessments, laboratory tests, and psychiatric and physical evaluations. During assessments, physicians inquire about accompanying symptoms and how they affect daily life, while taking into account potential underlying medical conditions or medications-related elements that may be linked to depressive behavior. Among symptoms associated with depression are persistent low mood, loss of interest or pleasure, changes in appetite or weight, sleep disturbances, psycho-motor changes, fa-

tigue, feelings of worthlessness or guilt, cognitive impairments, and recurrent thoughts of death or suicide.

Healthcare professionals frequently assess the severity of depression by employing rating scales such as the Geriatric Depression Scale (GDS) of Yesavage (Yesavage, 1988), Hamilton Depression Rating Scale (HDRS) (Williams, 1988), or the Patient Health Questionnaire–8 (PHQ–8) (Kroenke et al., 2009). These scales provide a standardized way to assess and measure the extent of depressive symptoms.

Table 1.1: Geriatric Depression Scale (GDS) questionnaire. Probable Depression: If five or more items in this column are answered as displayed, it indicates probable depression[1]

Items	**Question**	**Probable Depression**
1	Are you basically satisfied with your life?	No
2	Have you dropped many of your activities or interests?	Yes
3	Do you feel that your life is empty?	Yes
4	Do you often feel bored?	Yes
5	Are you in good spirits most of the time?	No
6	Are you afraid that something bad is going to happen to you?	Yes
7	Do you feel happy most of the time?	No
8	Do you often feel helpless?	Yes
9	Do you prefer to stay at home, rather than going out and doing new things?	Yes
10	Do you feel you have more problems with your memory than most?	Yes
11	Do you think it is wonderful to be alive?	No
12	Do you feel pretty worthless the way you are now	Yes
13	Do you feel full of energy?	No
14	Do you feel that your situation is hopeless?	Yes
15	Do you think that most people are better off than you are?	Yes

GDS is widely used for assessing depression in individuals aged 65 and older. It consists of a series of *yes/no* questions. Table 1.1 presents the questionnaire for the short form of the GDS, which consists of 15 questions, where if five or more items are answered as shown in the column *Probable Depression*,

[1]Adapted from Yesavage (1988).

it could indicate probable depression. Scores of 0–4 are considered normal, 5–8 indicate mild depression, 9–11 moderate, and 12–15 severe.

Table 1.2: Hamilton Depression Rating Scale (HDRS) items[2]

Items	Category	Description	Max Score
1	Depressed mood	Presence and severity of a sad or low mood.	4
2	Feeling of guilt	Feelings of guilt, self-blame, or worthlessness.	4
3	Suicide	Presence of suicidal thoughts.	4
4–6	Insomnia	Sleep disturbances, including difficulty falling asleep (early of the night), waking up in the middle of the night (middle of the night), or early morning awakening (early hours of the morning).	6
7	Work and activities	Changes in work, interests, or daily activities.	4
8	Retardation	Physical restlessness movements.	4
9	Agitation	Physical excessive movements.	4
10–15	Anxiety	Presence and severity of physical symptoms related to anxiety (psychic and somatic), such as tension, headaches, and gastrointestinal distress.	18
15–16	Loss of weight	Changes in appetite and weight loss.	6
17	Insight	Awareness of their depressive symptoms and condition.	2
Max total score			56

Another evaluation scale, the HDRS consists of several structured questions and observations made by a trained clinician during an interview (see Table 1.2). The assessment covers domains such as mood, feelings of guilt, suicidal thoughts, sleep disturbances, appetite changes, and physical symptoms (e.g., fatigue and agitation). Each item is scored based on the presence and severity of symptoms, and the total score is used to categorize the level of depression as follows: normal range (0–7), mild (8–16 points), moderate (17–23), and severe ($>$24).

The PHQ–8 is a self-administered questionnaire used to assess and monitor symptoms of depression (see Table 1.3). Each question asks the participants to rate the frequency of their symptoms over the past two weeks on a scale that includes the following options: not at all (0 points), several days (1 point), more than half the days (2 points), or nearly every day (3 points). Based on the answers to these questions, healthcare professionals can assess the severity of a person's depressive symptoms. This score ranges from 0 to 24, where the

[2]Adapted from Fleck et al. (1995)

[3]Adapted from Kroenke et al. (2009)

Table 1.3: Patient Health Questionnaire–8 (PHQ–8)[3].

Items	Category	Questions
1	Depressed mood	Little interest or pleasure in doing things
2	Anhedonia	Feeling down, depressed, or hopeless
3	Sleep disturbances	Trouble falling or staying asleep, or sleeping too much
4	Feeling of tiredness	Feeling tired or having little energy
5	Changes in appetite	Poor appetite or overeating
6	Feelings of guilt	Feeling bad about yourself, or that you are a failure, or have let yourself or your family down
7	Difficulty to focus	Trouble concentrating on things, such as reading the newspaper or watching television
8	Slowness/concern	Moving or speaking so slowly that other people could have noticed. Or the opposite, being so fidgety or restless that you have been moving around a lot more than usual.

cut-offs for severity are as follows: 0–4 no depression, 5–9 mild depression, 10–14 moderate, 15–19 moderately severe, and (>20) severe.

1.2.2 Alzheimer's disease

Speech and Language production

AD is characterized by progressive dementia, degeneration, and death of brain cells. AD symptoms include memory, behavioral and psychological impairments, and decline of cognitive functions related to communication deficits, i.e., the capability to produce coherent language (Knopman et al., 2021). AD is the most common form of dementia, affecting 2/3 of the total cases of dementia (Prince et al., 2015). Fluency of the patients' speech is impacted by the difficulty in accessing the semantic information intentionally produced by abnormalities in language production (Knopman et al., 2021; König et al., 2015). Cognitive deficits and behavioral disorders are common manifestations in AD patients. The patients tend to react aggressively, perceiving danger in everyday situations where none exists. These mood swings stem from alterations in their perception of reality. Furthermore, there is research suggesting that the diminished ability to experience emotions is linked to memory loss, potentially inducing anxiety and depression (Goodkind et al., 2010).

Traditionally, prosodic measures in dementia research have focused on temporal factors, intensity, voice quality, and variation in F0. Timing-based features have been shown to have an impact on AD patients, where several studies reported changes in interruptions (e.g., percentage and number of pauses, and articulation rate), rhythm, and voice periods. It is also characteristic for AD patients to show increased pauses and unvoiced segments, longer speech and phonation times, and decreased speech rate (Yang et al., 2022). Regarding prosody, differences in F0 during emotional expression have been observed. In addition to these, other acoustic descriptors such as formant frequencies and spectral-based features can provide contextualized interpretations of the acoustic information (Pulido et al., 2020).

Language production in AD patients implies changes related to cognitive and memory impairments. These changes include word-finding difficulties, reduced vocabulary, impaired sentence construction, fluency issues, decreased verbal memory, and even echolalia/palilalia[4] (Wallesch, 1990) in advanced stages. Patients might experience difficulties in auditory comprehension, social withdrawal, and initiating or responding to conversations. Simple tasks like naming objects can also become challenging (Taler and Phillips, 2008). Subsequently, features that aim to describe these changes are categorized into four groups: syntactic complexity, lexical richness, informative, and Part-of-Speech tagging (PoS) (Lindsay et al., 2021). Syntactic complexity features focus on sentence structure and include metrics such as sentence length, word length, and the presence of non-standard words. AD patients tend to produce shorter sentences with simpler structures, difficulty using pronouns correctly, and reliance on non-standard words. Lexical richness assesses vocabulary diversity and includes features such as type-token ratio and age of acquisition of a word (Juhasz, 2005)[5]. AD patients often exhibit a decline in vocabulary richness, struggling to recall and use a wide range of words. Informative features evaluate speech content, measuring lexical density, interjections, and

[4]Echolalia is the repetition of phrases or sounds others have said, while palilalia is the repetition of one's own words or sounds

[5]It is normally computed according to an established dictionary.

repetitions. AD patients tend to produce less content-rich and detailed narratives, with increased use of interjections and fewer references to keywords or information units. PoS features categorize words based on their grammatical function and investigate word usage. AD patients may use certain word types more or less frequently, such as pronouns and conjunctions, and exhibit alterations in phrase structures. These features help identify language changes associated with AD (Lindsay et al., 2021).

Clinical diagnosis

AD diagnosis typically involves a comprehensive assessment that includes several steps and medical evaluations. It is important to note that diagnosing AD often requires a post-mortem examination of the brain tissue for a conclusive diagnosis (DeTure and Dickson, 2019). However, clinicians can make a probable diagnosis based on a combination of clinical evaluation, cognitive tests, and other medical tests (Honig and Mayeux, 2001; Nordberg, 2015). Physicians analyze signs, symptoms, and anamnesis in the clinical evaluation while consulting with family and friends. Cognitive tests involve comprehensive assessments and neuropsychological tests for memory, problem-solving, and language skills. Laboratory tests (e.g., blood work) are conducted to identify potential contributing factors such as thyroid issues or vitamin deficiencies. Brain imaging techniques such as Magnetic Resonance Imaging (MRI) or Computerized Tomography (CT) scans assess brain structure and exclude other conditions. Physicians also rule out other health concerns that may mimic AD symptoms and assess memory problems through neuropsychological evaluations and interviews with relatives. This rigorous diagnostic approach helps precisely understand the patient's condition (DeTure and Dickson, 2019).

Regarding the assessment of AD, this thesis focuses more on cognitive tests. These evaluations are conducted by neuropsychologists with expertise in assessing cognitive functioning and its relationship to brain health. The Mini-Mental State Examination (MMSE) is a standard scale to assess the cog-

[6]Adapted from Folstein et al. (1983)

Table 1.4: Mini-Mental State Examination (MMSE) categories[6].

Category	Description	Max Score
Orientation to time	Assesses awareness of time (e.g., year, date, and day).	5
Orientation to place	Evaluates understanding of location (e.g., place or streets).	5
Registration	Ability to listen to and repeat back-named prompts or items.	3
Attention and Calculation	Assesses the ability to perform mental calculations or engage in attention-demanding tasks (e.g., counting backward by sevens).	5
Recall	Measures the ability to remember items or information that was previously presented.	3
Language	Participants are asked to name familiar objects (e.g., pencil) to assess language and object recognition skills.	2
Repetition	Ability to repeat a phrase or sentence back.	1
Complex commands	Complex instructions, such as drawing a specific figure or following multi-step commands.	6

nitive function of AD patients, which is a 30-point scale, where classically, scores of over 24 indicate normal cognition (Folstein et al., 1983), although this threshold is adjusted according to the region where the test is administered, i.e., it is different in Europe vs. Latin America due to education and cultural differences (Katsanos et al., 2023). It consists of questions and tasks that evaluate several cognitive dimensions, including orientation, memory, attention, language, and spatial skills (see Table 1.4). Depressive symptoms are frequently observed in AD patients (Lyketsos and Lee, 2003; Olin et al., 2002; Wragg and Jeste, 1989). According to (Lyketsos and Lee, 2003), approximately 80% of AD patients can experience depression during the course of the disease. Diagnosing depression in AD patients can be challenging due to overlapping symptoms and communication difficulties, which is crucial since depression can worsen cognitive deterioration. It is based on the same criteria for diagnosing depression in individuals without dementia. In some cases, healthcare professionals may use standardized depression rating scales such as the GDS or HDRS to assess depression severity (See Section 1.2.1).