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TOPICAL REVIEW

Data-Driven Analysis of Patients' Body Language in Healthcare: A Comprehensive Review

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ABSTRACT *Body language* refers to the unspoken communication conveyed through human body actions like body movements and postures, limb gestures, and facial and other bodily expressions. It acts as a transparent medium, exposing an individual's emotions, attitudes, true thoughts, intentions, and physical and mental health states. A person may express pain using hand movements or other bodily cues, their facial expressions potentially offering insights into the intensity of the pain. Additionally, various diseases and pains can induce abnormalities in body movements, postures, and expressions, signaling distress or discomfort. Therefore, investigating the cause-effect relationships between diseases/pains and patients' abnormal body language holds significant relevance, promising to enhance our understanding and management of these conditions. This importance has been reflected in numerous healthcare and artificial intelligence (AI) research articles. AI studies investigate this and related topics by detecting, recognizing, and analyzing patients' abnormal activities and body actions using machine-learning techniques. However, most AI studies do not consider comprehensive domain knowledge that describes a complete and accurate list of patients' abnormal actions caused by a disease or pain. Though these results appear consistent and stable from an AI outlook, they fall short when viewed through the prism of healthcare, primarily because the limited domain knowledge incorporated in the AI studies makes the findings partially incomplete. To overcome these drawbacks, this paper comprehensively reviews healthcare and medical studies centered on patients' body language from an AI outlook. It presents a thorough descriptive and exploratory analysis of the findings, yielding a more accurate and comprehensive understanding of the causational connections between diseases and abnormal body actions and the strength of the evidence supporting these connections. The analysis enables us to define "disease-to-abnormality" and "abnormality-to-disease" mappings that result in building exhaustive and accurate lists of abnormal body actions induced by diseases and pains as well as lists of diseases and pains causing particular abnormal body actions. The generation of these lists is assisted by the concepts of "correlation strength index" and "strongly correlated selection" defined in this paper. The paper's results have significant implications for developing machine learning systems that can more accurately analyze patients' physical and mental health states, correctly identify external signs and symptoms of diseases, and effectively monitor health conditions.

INDEX TERMS Body language, disease, pain, body movement, body posture, facial expression, data analysis, causational relationship, correlation strength.

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I. INTRODUCTION

Body language is a type of nonverbal communication in which physical behaviors – visible bodily actions instead of words – are used to express or convey information. Such behaviors can be gestures, stances, and movements of any part of the body or whole, including facial expressions, body postures and movements, hand gestures, eye movements, touch, and tone of voice [1]. Mehrabian ([2]) established that the total impact of a message is about 7% verbal (words only), 38% vocal (including tone of voice, inflection, and other sounds), and 55% nonverbal; in other words, the nonverbal communication amount to an astounding 93%. Birdwhistell ([1], [3]) found that the verbal component of a face-to-face conversation is less than 35%, and over 65% of communication is done nonverbally. Many other researchers also concluded that most communication among individuals involves physical symbols or gestures since the interaction of body language facilitates speedy information transmission and understanding (for instance, see [4]). According to [5], body language speaks more and better content than verbal language. Nonverbal communication reveals a person's true thoughts, feelings, and intentions. Because people are not always aware that they are communicating nonverbally, body language is often more honest than an individual's verbal statements [6].

The impact of body language on interpersonal interactions and communications in different sectors, such as education, politics, security, and trade, has been extensively studied. For instance, papers [7], [8], and [9] examine students' engagement, attention, and other *teaching and learning-related problems* through body language. The recognition of human activities, gestures, and emotional expressions from *security* perspectives is studied in [10] and [11]. Articles [12] and [13] discuss the effect of body language on *political aspects*. The role of emotions and gestures in *commercial and business communications* is analyzed in [14], [15], and [16].

Reading nonverbal cues or signs helps interpret peoples' *physical and psychological states*, such as health conditions, feelings, and emotions. For example, a sick individual might express discomfort and emotions through facial cues, body postures, or gestures denoting their pain's location and intensity. Body language can often reveal external indicators of disease; someone with a toothache, headache, or stomach pain frequently presses on or massages the affected areas while displaying evident pain through facial expressions and specific body postures. Several diseases also cause abnormal body actions. For example, Parkinson's disease can result in involuntary movements like hand tremors, rigidity, and difficulties with balance and coordination. It is well-documented that the abnormal body language of patients has been extensively researched, as referenced in [17], [18], [19], and [20]. Recent advances in artificial intelligence (AI), especially machine learning, allow the use of AI-based technologies in almost all aspects of human life. AI plays a crucial role in transforming traditional healthcare into smart healthcare, making it more efficient, convenient, and personalized [21]. Smart healthcare systems involve automated health monitoring, intelligent diagnosis and treatment, optimized hospital management, best health decision-making, and AI-powered medical research. Analyzing patients' body language using machine learning techniques enhances key dimensions of such systems by intelligently monitoring and evaluating patients' health conditions, identifying external signs and symptoms of diseases and pains, and diagnosing diseases through abnormal body actions.

A primary challenge in employing machine learning approaches for analyzing abnormal body language in patients is the insufficient comprehensive expertise in the healthcare and medical field concerning the vast array of abnormal movements, postures, gestures, and facial expressions induced by various illnesses and pain conditions. The standard method for investigating body abnormalities in AI research involves selecting specific, albeit not comprehensive, abnormal body actions based on particular criteria. Despite this selection process being initiated with a wide-ranging data set, sophisticated data preprocessing and feature engineering techniques being leveraged, and robust machine learning methods and algorithms being employed, resulting in high-performance outcomes, the scope of the findings remains limited by the predefined selection criteria. While these results appear consistent and stable from an AI standpoint, they fall short when viewed through the prism of healthcare, primarily because the limited domain knowledge incorporated in the AI studies makes the findings partially incomplete. Consequently, these AI-driven intelligent systems exhibit limitations: they cannot fully identify all abnormal actions induced by diseases occurring across diverse body regions, finely discern patterns of abnormalities or accurately analyze the signs and symptoms of diseases and pains. We refer the reader to papers [22], [23], [24] for more detailed information.

To mitigate such limitations in AI studies, it is imperative to perform an extensive evaluation and synthesis of scholarly articles in the healthcare domain, focusing on exploring the cause-effect relationships between diseases/pains and abnormal body language exhibited by patients. This body of research, spearheaded by healthcare professionals, has pinpointed potential abnormalities in movements, postures, gestures, and expressions, which occur in different body regions due to diseases and pains. These findings are grounded in meticulous patient evaluations in trustworthy clinical or laboratory environments, thereby substantiating the view that the observed abnormal body actions are the causational effects of the corresponding diseases. Hence, AI researchers are positioned to develop more thorough and precise databases of potential abnormal body actions caused by diseases and pains cost-effectively and efficiently. Utilizing the gathered and synthetically generated data (for training purposes), these abnormalities aid in developing more accurate, reliable, and comprehensive machine learning models. These improved models are adept at scrutinizing and overseeing patients' health through a detailed body language analysis, offering a promising avenue for enhancing healthcare monitoring and intervention strategies.

In the current research, we comprehensively review and study healthcare (medical) papers investigating sick people's and healthcare patients' body language using different descriptive and exploratory data analysis techniques. This analysis of the medical investigations is critical since they provide more authentic and comprehensive domain knowledge on the *causational relationships* of diseases and pains with body language, which help to develop better data acquisition and preprocessing techniques, machine and deep learning-based segmentation, detection, recognition, and evaluation methods and algorithms for patients' body language analyses. In our review and analysis, we follow the following methodology, summarized in Figure 1.

Stage 1: Paper Search and Selection: We conduct a comprehensive search for medical/healthcare (MD) research and review papers in electronic databases such as PubMed, ScienceDirect, and SCOPUS. These papers explore the relationships between various diseases or pain and patients' abnormal body language. The search is conducted using keywords such as "*condition*," "*disease*," "*pain*," "*body*," "*head*," "*neck*," "*shoulder*," "*face*," "*eye*," "*limb*," *"upper limb," "lower limb,"*"*arm*," "*hand*," "*leg*," "*foot*," "*finger*," "*abnormal*," "*movement*," "*pose*," *"posture,"* "*gesture*," "*expression,*" and their combinations that highlight the cause-effect relationships between diseases or pain and abnormal body actions.

Stage 2: Paper Classification: Recognizing that patterns of body action abnormalities caused by diseases or pain differ across various body parts (i.e., each part can exhibit distinct abnormal movements, postures, expressions, and gestures), we categorize the selected papers according to the specific body parts they have examined. These categories encompass the body, head, neck, shoulders, face, eyes, upper limbs, and lower limbs.

Stage 3: Paper Review: In alignment with the objectives outlined in this study, our review of the selected papers concentrates explicitly on identifying and extracting information relevant to the considered diseases or pain conditions, the abnormal body actions caused by these conditions, and the strength of these causational relationships.

Stage 4: Finding Summarization: For readability and ease of further analysis, the findings from the reviewed papers, extracted based on the predefined criteria, are organized in tables categorized by body parts. Each table presents rows listing the paper reference, the identified disease or pain, associated abnormal body actions, and the strength of their cause-effect relationships.

Stage 5: Analysis of Findings: This stage begins with examining the statistical characteristics of various diseases, pains, and abnormal body actions. Then, the findings associated with a specific disease (disease group) or pain (pain group) are synthesized to identify the correlated abnormal body actions (poses, movements, gestures, expressions). To quantify these relationships, we introduce the *Correlation Strength Index* (CSI). This index aggregates various evidence strengths to assign a unified value to each cause-effect relationship based on the number of papers discussing the condition and the correlation strength. Furthermore, we propose two concepts for more accurately identifying abnormalities and health conditions: the *Strongly Correlated Abnormalities Selection* (SCAS) and the *Strongly Correlated Diseases Selection* (SCDS). The former identifies the most comprehensive and reliable sets of abnormal body actions associated with specific diseases or pains, while the latter determines the most probable diseases and pains causing particular abnormal body actions.

Stage 6: Conclusions: In this concluding stage, we present a detailed summary of our review study, highlighting the significance of our data-driven approach in analyzing the literature. We also acknowledge the limitations of the current research and suggest several prospects for future research.

The paper is organized as follows. Section II provides an initial overview of the content of the reviewed papers and analyzes the complexity of studying the causational relationships of diseases and pains with abnormal body actions. Section III reviews medical and healthcare papers focused on disease/pain and body language relationships. Section IV precisely summarizes the findings in the "abnormality" tables. Detailed data analyses of the statistical and relational properties of diseases/pains and abnormal body actions are provided in Section V. Lastly, Section VI concludes the current study, explains its limitations and describes the succeeding research directions.

II. PRELIMINARY OBSERVATION

This study thoroughly reviews medical and healthcare papers on patients' body language caused by diseases and pains. From initially collected 780 articles that mention diseases, pains and their relationships to patients' body postures and movements, we selected 129 papers that discussed the *causational relationships* of diseases and pains with ***abnormal body language elements***(a.k.a. ***actions***), i.e., abnormal movements, postures, gestures and expressions performed by the body or any body part. Figure 2 illustrates the initial observation of the reviewed *papers' network*, i.e., the relationships of the diseases, pains, body language, and other essential keywords occurring in these papers. This graph is constructed using the VOSviewer [25] from the information (keywords) provided in the titles and abstracts of the papers included in the Mendeley Reference Manager [26]. The graph consists of 258 nodes and 2132 edges in 16 clusters. The nodes in the graph represent all the keywords selected, and each node size indicates the total number of occurrences of the corresponding keyword in all papers. The keywords closely related to one another are grouped into clusters of different colors. The edges indicate the relations between keywords. Due to the high number of keywords present, some nodes are congested in a single location, resulting in some keywords not being displayed (we refer the reader to https://bit.ly/md-network-diagram to view a more detailed chart). Here,

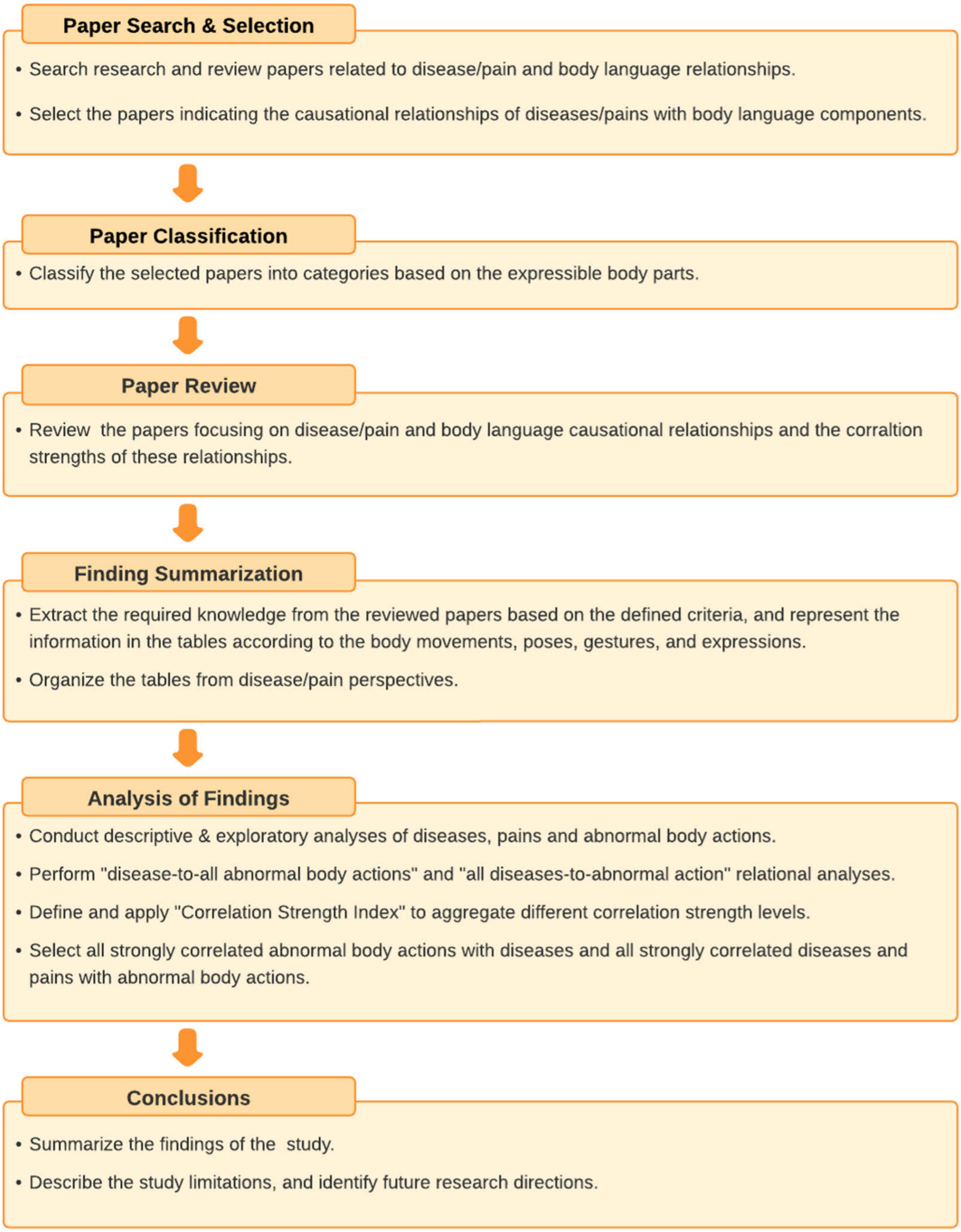

FIGURE 1. The review and analysis methodology.

we can observe that, though the closely related keywords are clustered, the represented relationships of diseases and pains with body postures, movements, expressions, and gestures are still very complex and highly unstructured, which challenges establishing structured and accurate relations of diseases and pains with body language elements. Hence, this work focuses on achieving this goal through extensive data analysis.

III. PATIENTS' ABNORMAL BODY LANGUAGE

This section reviews healthcare and medical papers, primarily emphasizing the causational connections between diseases/pains and patients' abnormal body language. Instead of delving into the research methodologies, we gauge the strength of the evidence supporting these connections. This review approach allows us to curate a precise set of body language components like movements, postures, gestures, and expressions tied to specific diseases or pain, which provides essential domain knowledge for AI studies centered around patients' body language analysis. Our reviews concentrate on abnormal movements, postures, gestures, and expressions about each expressive part of the body, including the head, neck, shoulders, face, eyes, lower limbs, upper limbs, and the body in general.

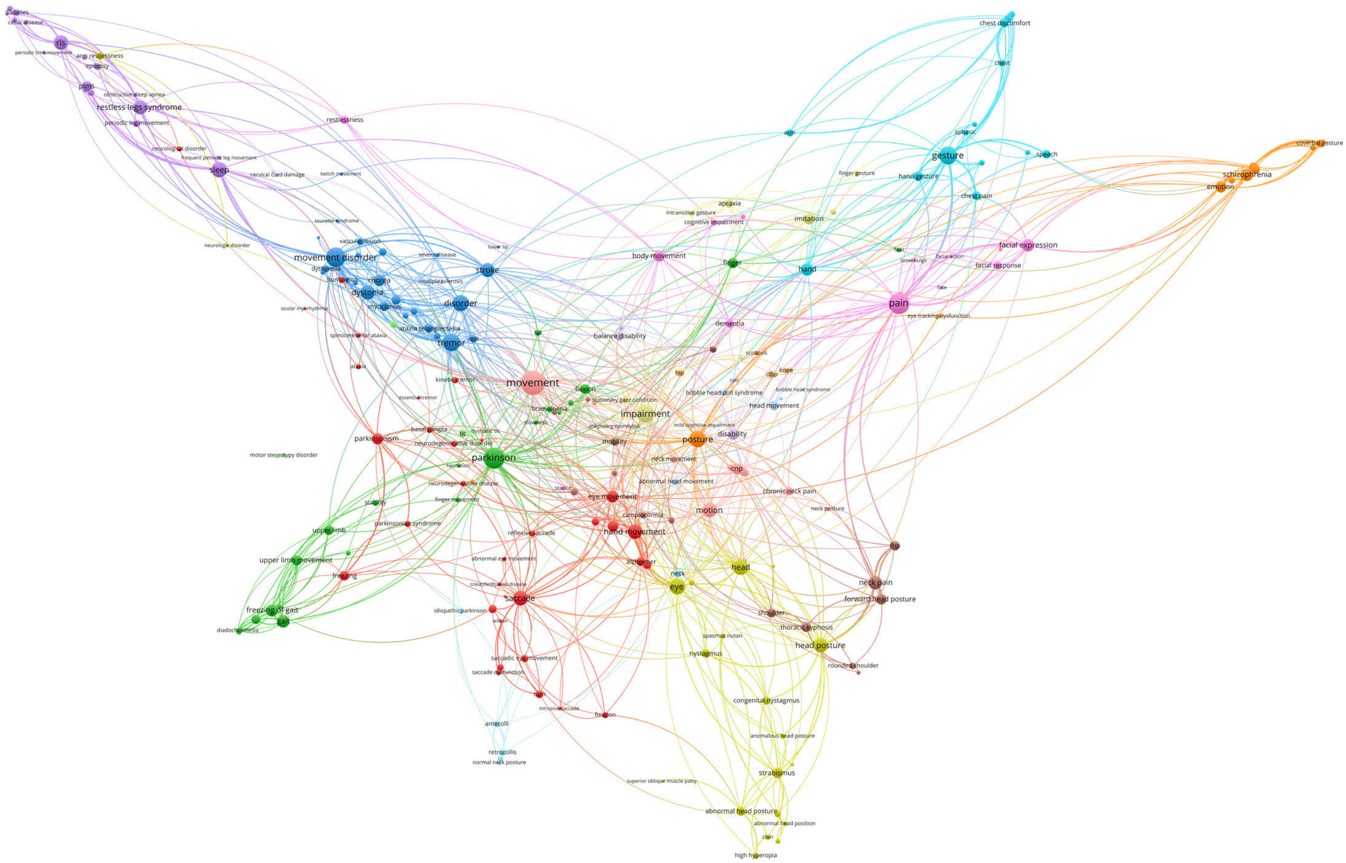

FIGURE 2. The network of the reviewed papers.

A. ABNORMAL BODY POSES AND MOVEMENTS

The following papers demonstrate that various abnormal body poses and movements can result from different brain and neurological disorders such as Parkinson's disease (PD), Huntington's disease (HD), Gilles de la Tourette syndrome (GTS), dystonia, etc. Paper [27] analyzes GTS patients' body movements, finding they move more frequently during all sleep stages than non-GTS individuals. Particularly, twitching in REM sleep is significantly elevated in GTS. Study [28] uses the static charge-sensitive bed method to analyze sleep movements in PD patients. The results show that PD patients have less sleep movements and experience Parkinsonian tremors about half the time in bed, which ceases when they fall asleep. Work [29] studies sleep's impact on involuntary movements in 52 patients with Parkinson's, Huntington's, and other movement disorders, finding most exhibit tremors, chorea, spasms, and tics that can recur during sleep.

Study [17] reviews several studies that analyze the impact of PD on body poses, movements, and facial expressions. It concludes that PD patients show abnormality in these areas, including delayed and reduced movements, impaired execution, rigid facial expressions, and tremors. Research [30] studies balance regulation in PD patients, demonstrating they keep stability through leg flexor activation but struggle with balance when their eyes are closed. Paper [31] assesses how imitating meaningless finger, hand, and foot gestures varies with left and right brain damage. It finds that left brain damage impacts hand and foot gesture imitation more than fingers, while right brain damage chiefly affects finger gestures, with more significant influence on feet than hands. Study [32] evaluates ataxia-telangiectasia (A-T) symptoms in 53 adults, focusing on movement problems. It finds that patients exhibit co-contraction, myoclonus, tremors, dystonic spasms, tonic activity, and abnormal postures. Most commonly observed are tremors (43%), dystonia, and subcortical myoclonus (86%). Paper [33] studies early PD-related changes in mediolateral postural control, focusing on body sway, coordination, and control during 80-degree lateral gaze shifts. The study found that patients showed larger lower back movements and smaller head movements during gaze shifts.

The following papers suggest that physical disorders and pain can lead to abnormal body postures and movements. Article [34] examines the differences in human body posture (HBP) between healthy individuals and those with conditions like coxarthrosis, discopathy, scoliosis, depression, and chronic fatigue syndrome. The study reveals substantial disparities in HBP and a significantly reduced correlation between body sides in diagnosed patients compared to healthy people. Research [35] explores the relationship between gestures and verbal communication, particularly their role in expressing different types of pain. It distinguishes three gesture functions: pointing at the body, demonstrating movements or body positions, and describing aspects of pain. Study [36] investigates the body reactions of preterm infants to clustered care and pain. It notes extensor movements (e.g., arm, leg, and tongue extension, hand-on-face) and flexor movements (hand-to-mouth, leg movements) as responses to these stimuli, with yawning indicating stress.

Paper [37] explores sitting postures in healthy individuals and those with non-specific chronic low back pain (NS-CLBP). The study finds no posture difference between groups during regular sitting. However, depending on their condition, NS-CLBP patients display either an excessively inward (lordotic) or convex (kyphotic) lower lumbar spine curvature. These patients also show limited ability to alter posture from a regular sitting to a slumped position. Work [38] examines how body movements indicate pain in cognitively impaired older people. It identifies five movements (restlessness, rubbing, guarding, rigidity, physical aggression) with strong evidence and another five (bracing, decreased mobility/stopping, flinching, pacing, poor posturing) with moderate evidence of being pain indicators.

B. ABNORMAL HEAD POSES AND MOVEMENTS

The research articles below demonstrate that abnormal head positions and movements can be attributed to ocular disorders such as nystagmus, strabismus, Duane syndrome, and Brown's syndrome. Paper [39] studies the ocular origins of abnormal head positions, identifying eight primary causes: compatibility, nystagmus, congenital esotropia, foveal fixation, cosmetic ocular motor apraxia, nutans spasm, and astigmatism. Study [40] analyzes irregular head postures from various disorders using realistic recording methods, revealing how the mechanical properties of the head/neck system relate to the frequency of head dyskinesias in these disorders. It highlights notable differences between adaptive dyskinesias caused by irregular eye movements and passive dyskinesias due to neck hypotonia. Paper [41] studies the factors affecting head postures in patients with congenital nystagmus. Sixteen participants' head and eye movements are tracked across different gaze orientations. Four patients display varying head positions, five have a singular posture, and six postures align with the minimum intensity zone.

Study [42] examines the link between abnormal head posture and far-sightedness, with patients adopting a chin-down position for focus. Work [43] investigates the origin of nystagmus in children with irregular head postures and strabismus, proposing a diagnostic approach. It reveals that congenital nystagmus (62%) triggers "gaze null" (slow eye movements), manifest latent nystagmus (32%) leads to "adduction null" (eye fixation at extreme motion range), while spasmus nutans and strabismus cause 3% each. Paper [44] studies the clinical features of common eye-related causes and abnormal head positions (AHP). The main causes of AHP include fourth cranial nerve palsy (33.7%), Duane retraction syndrome (21.5%), sixth cranial nerve palsy (11%), nystagmus blockage syndrome (9.8%), and Brown syndrome (6.7%). Review [45] analyzes the causes of abnormal head postures in various illnesses. It finds that symptoms like chin elevation, head turn, and tilt indicate muscular torticollis, a non-ocular illness. Similarly, ocular diseases like torticollis, nystagmus, incomitance, and Duane syndrome also result in abnormal head positions, such as face rotations and chin deviations.

Neurological and brain disorders can also contribute to abnormal head postures and movements. Paper [46] compares head posture between craniomandibular disorder (CMD) patients and healthy individuals, as well as between different CMD pain types. It refutes the notion that improper head position is linked to painful CMD illnesses, even when combined with cervical spine issues. Case study [47] details a 12-year-old with left abducens nerve palsy, hand tremors, difficulty in finger-nose test and tandem walking, hyperreflexia, and an extensor plantar. Another case study [48] explores a patient with bobblehead doll syndrome and external ventricular drainage, linking the condition to abnormal head movements. Work [49] explores how various diseases, including ophthalmologic, orthopedic, and neurologic, impact children's disordered head postures. The study finds a correlation between stiff neck muscles and head tilt in two cases attributed to superior oblique muscular palsy and orthopedic-related neck muscle contracture. Paper [50] studies the potential link between temporomandibular disorders (TMD) and different head positions. It finds no significant association between forward head posture or head tilt and TMD.

Review [51] outlines ALS patients' clinical features, differential diagnosis, etiology, and dysarthria treatment. It explores flaccid, spastic, and mixed dysarthria. Flaccid symptoms include impaired articulation, tongue weakness, weak voice, and deficient reflexes. Spastic dysarthria presents with a non-wasted tongue, slurred speech, rapid reflexes, and emotional instability. Paper [52] explores Huntington's disease's clinical characteristics and differential diagnosis, including rigidity, chorea, tics, and motor im-persistence. Despite commonly observe in HD patients, it is not linked with disease severity. Choreaform motions stand out as the most distinctive feature of HD. Study [53] evaluates the features, causes, diagnosis, and treatments of movement disorders related to brain tumors. It mentions four disorders: hemichorea-hemiballism (one-sided body motions), symptomatic hemidystonia (affects same-side face, arm, leg), hemifacial spasm (HFS; unilateral contractions in facial muscles), and parkinsonism, which is rarely associated with brain tumors. Body pains, particularly neck pain, can also affect head postures and movements. Paper [54] assesses head and neck positioning in whiplash patients, including the effect of cranio-cervical flexion. Findings reveal whiplash patients have a reduced active range of motion compared to healthy individuals but no significant difference in position-matching accuracy.

C. ABNORMAL NECK POSES AND MOVEMENTS

Research papers relate abnormal neck poses and movements to conditions such as arthritis, Parkinson's, and dystonia. Paper [55] investigates cervical spine movement limitations in ankylosing spondylitis (AS) patients, highlighting limited lateral flexion. Torticollis, a spasmodic contraction of neck muscles causing head tilt and rotation, is symptomatic of an underlying disorder rather than a diagnosis itself. Study [56] examines voluntary neck movements in cervical dystonia (CD) patients, finding that they perform these movements at a lower velocity and with reduced amplitude compared to controls. Anti-dystonic movements take longer to perform, and while flexion and extension movements also require more time, other kinematic variables remain normal. Paper [57] updates the prevalence of axial postural deformities like camptocormia, antecollis, Pisa syndrome, and scoliosis in Parkinson's disease. Work [58] investigates retrocollis in Parkinson's patients, finding higher neck rigidity scores in those with retrocollis and antecollis compared to those with normal neck postures.

Study [59] examines how head posture relates to neck pain and disability. It finds that patients with neck pain have significantly smaller craniovertebral (CV) angles than healthy individuals. The study reveals a moderate negative correlation between CV angle and neck disability, indicating that a lower CV angle, associated with more forward head posture, correlates with higher disability rates. Report [60] reviews head posture assessment in neck pain patients, finding unclear evidence of differences in head pain components compared to those without symptoms. Paper [61] finds that teenagers with neck pain exhibit significantly lower endurance in neck flexors and extensors and decreased forward head posture. Research [62] examines the relationship between range of motion, chronic neck pain, and posture in young adults compared to pain-free individuals. It finds significant differences in frontal plane alignment and cervical angles, suggesting a correlation between these factors. Study [63] investigates active neck movement variability in chronic neck pain (CNP) sufferers compared to healthy individuals using helical axis measures. The study finds reduced movement variability in CNP individuals, particularly in flexion, extension, and rotation movements. Review [64] analyzes the relationship between forward head posture (FHP) and neck pain, finding that age significantly affects this relationship. It concludes that those with neck pain display more FHP than those without, and a strong association exists between FHP and neck pain in adults and the elderly.

D. ABNORMAL SHOULDER POSES AND MOVEMENTS

Shoulder abnormalities, including frozen and rounded shoulders and shoulder pains, can be caused by neurological and physiological conditions like Parkinson's disease (PD) and kyphosis. Work [65] explores the notable presence and link of frozen shoulders in PD patients. It finds an increased incidence of shoulder issues, mainly frozen shoulder, among the PD population. In some cases, frozen shoulder surfaces are the initial symptom of PD, appearing up to two years before common disease features. The paper concludes that Parkinson's disease should be added to the list of causes of frozen shoulder. Review [61] examines the relation between postural issues such as forward head posture, rounded shoulders, and increased thoracic kyphosis. It finds significant associations between cervical lordosis and thoracic kyphosis, as well as rounded shoulders and increased thoracic kyphosis.

Paper [77] examines the impact of postural changes and increased kyphosis (camptocormia) in PD on shoulder pathology, specifically adhesive capsulitis and shoulder stiffness. It finds that severe postural impairment in PD patients, resulting in higher thoracic kyphosis and reduced trunk mobility, can lead to humeroacromial impingement syndrome and capsulitis. Paper [78] explores the diagnosis and differentiation of a frozen shoulder from other painful shoulder conditions, analyzing current theories on the causes and effectiveness of various treatment methods. The paper identifies three main symptoms of a frozen shoulder: gradual shoulder stiffness, severe constant pain, including at night, and almost total loss of passive and active external rotation. It also recognizes the role of head, neck, and shoulder posture in cervical pain dysfunction syndromes.

E. ABNORMAL FACIAL EXPRESSIONS

Individuals suffering from brain disorders, injuries, and depression often exhibit various abnormal facial expressions, including negative emotions and emotional deficits. Paper [66] uses a new microcomputer method to analyze smiling behavior differences in PD patients versus a control group. It found that the PD patients smiled less frequently and with less mouth opening when watching cartoons. Work [67] assesses schizophrenia patients' ability to perceive and express universally recognized facial emotions and their sensitivity to these expressions. Despite broad impairments, patients show a susceptibility to fear and anger emotions. Paper [68] assesses facial expressions related to emotional deficits in schizophrenic and depressed patients compared to nonpatients. Both patient groups show impairments in all expressive aspects, with minor differences: depressed individuals display fewer spontaneous other-than-happiness emotions but seem more expressive overall. Work [69] experimentally verifies that facial responses to pain are more pronounced in dementia patients than in healthy controls, particularly at higher stimulation intensities. Paper [70] presents a case study on Parkinson's disease, detailing the progressive decline in speech quality and lip and jaw mobility as the disease advanced. Study [71] investigates methods for improving communication between caregivers and cognitively impaired patients. It finds that Lewy body disease patients' happiness remains stable despite factors like age and disease duration, but their ability to recognize fear is compromised. A meta-analysis was conducted to evaluate facial emotion recognition, a critical social cognition skill, in adult patients with traumatic brain injury (TBI).

Patients experiencing different types of pain often manifest abnormal facial expressions. Research [66] examines the association between facial expressions and pain in adults and children. It finds that detailed analysis of facial activity helps understand various aspects of pain not covered by self-report measures. For infants, facial activity is the most reliable pain indicator. Paper [67] uses the Facial Action Coding System (FACS) to identify four facial expressions – lowering the brow, pressing the lips, parting the lips, and turning the head – associated with myocardial infarction in chest pain patients, thus aiding in its diagnosis. Report [68] reviews pain assessment's history and social influence through facial expressions. It studies the structure of facial pain expressions across age groups and explores the use of computer-based facial assessment for adult and pediatric pain. The report notes that patients may downplay their pain due to fear or reservation, leading healthcare providers to underestimate pain levels. Study [69] examines healthcare providers' use of face scales and facial expression analysis to accurately gauge patients' clinical pain, highlighting facial expressions as the most sensitive nonverbal pain indicator. Paper [70] assesses the accuracy of facial expressions in pain scales for elderly dementia patients. Those scales describing specific facial actions associated with pain demonstrate higher sensitivity, consistency between raters, and validity.

F. ABNORMAL EYES MOVEMENTS

It is also valuable to examine eye abnormalities independently of facial expressions as they could indicate the presence of ocular and neurological issues. The subsequent studies establish a connection between brain damage, neurological disorders, and abnormal eye movements. Study [71] examines rapid eye movements (saccades) in mild to moderate idiopathic PD patients, comparing reflexive saccades with those to remembered locations. PD patients exhibit dysmetric saccades with a multi-stepping pattern towards remembered locations, though peak velocity, duration, and latency were similar to controls. Work [72] examines the delay in initiation and increased intrusive saccades in AD patients' eye movement without amplitude or velocity differences, linking these changes to heightened cognitive impairment. Paper [73] describes the oculomotor features of significant age-related movement disorders, including PD, HD, dementia, and other neurodegenerative disorders.

Review [74] summarizes recent research addressing eye movement issues in psychiatric diseases, particularly schizophrenia, to genetic and pharmacological factors. Paper [75] examines the link between saccade performance and turn impairments in Parkinson's disease. PD patients perform more, yet impaired saccades during turns, with decreased amplitude, particularly in 180-degree turns. Report [76] Report [95] reviews studies on saccadic eye movement in Parkinson's disease (PD), discussing parameters like latency, amplitude, velocity, and gain. It also explores the link between saccadic performance, neural circuitry, and cognitive processes in PD patients. Paper [77] discusses alterations in basic eye movements and complex visual tasks related to Alzheimer's disease. Work [78] summarizes key oculomotor anomalies in Parkinson's disease and related genetic syndromes. The study notes that abnormal voluntary saccades are present in the early stages, with visually guided saccades being affected later. Common deficits include saccadic hypometria, reduced accuracy, and increased latency. Additionally, PD patients often display extensive square wave jerks and have difficulty inhibiting reflexive saccades during required voluntary mirror saccades.

G. ABNORMAL UPPER LIMB MOVEMENTS

Numerous research efforts have been undertaken to examine the impact of neurological disorders, brain damage, and brain disorders on the movements of a patient's arms, hands, and fingers. Work [79] explores mobility issues in Tuberculous Meningitis (TbM), noting (1) prevalent generalized chorea in the tongue, hands, and feet, (2) varying dystonic posture in the upper left limb and high amplitude head tremor while seated, and (3) mixed dyskinesias with dominant facial and lower limb dystonia, right-hand posturing, and semi-rhythmic upper limb movements, mainly on the left. Research [80] analyzes praxis errors in 119 stroke patients, with negligible differences noted between those affected in the left or right hemisphere regarding the frequency and severity of apraxia for intransitive gestures, according to Roy's model [81] of limb praxis. Report [82] studies upper-limb movement abnormalities in ataxia-telangiectasia, finding age unrelated to tremor severity. It suggests that the disease is characterized by conventional cerebellar dysfunction and implicates a link between basal ganglia and cerebellum in the observed upper-limb irregularities.

Study [83] explores gesture imitation for early dementia diagnosis in the elderly, finding bimanual gesture imitation to be non-specifically impaired in roughly half of the patients with mild dementia. However, finger gesture imitation is particularly more impaired in patients with early Lewy body dementia (DLB) compared to AD or vascular dementia (SVaD). Paper [84] examines how aging affects finger motor skills in Multiple Sclerosis (MS) patients relative to disease duration and the Expanded Disability Status Scale (EDSS). A total of 96 MS patients undertake rapid and metronome-paced finger movements. Their performance is compared to norms and correlated with age, disease duration, and EDSS. The study finds that many patients perform below age-normal standards, with a higher chance of this among more disabled individuals. Age significantly correlates with glove parameters, with older, less disabled subjects performing worse than younger ones, while younger, more disabled subjects match older subjects' performance.

The impact of PD and AD on upper limb movements is analyzed in the following studies. Paper [85] examines cortical electroencephalographic potential in Parkinson's patients using scalp electrodes during two joystick movement tasks.

Normal subjects showed more potential before random-choice movements, but patients had consistent amplitude in both tasks, suggesting abnormal self-selection processes in PD. Research [86] examines sequential finger movements in PD patients, revealing difficulties across all motor tasks. Patients find the sequential finger-tapping task significantly more challenging than other tasks and struggle more with individual finger movements than gross hand movements.

Work [87] studies the decline in motor function in PD patients, focusing on speed and amplitude changes during task completion. Both normal subjects and patients perform finger movements faster during flexion than extension, with longer pauses after flexion. PD patients exhibit slower and less robust finger movements, particularly during flexion and transition from flexion to extension. Movement speed further slows down during individual finger oppositions. Research [88] examines early preclinical detection of PD by assessing changes in movement electro-physiological parameters. It studies individual organ movements (eyes, head, or hand) and their coordination. Tests show similar results for individual movements in PD patients and healthy individuals but significant differences in movement coordination. Paper [89] investigates how movement frequency and medication affect unconstrained index finger movements in PD patients. Results reveal that movement frequency significantly influences hypokinesia during repetitive movements and may cause hesitations and arrest during upper limb bradykinesia tests in PD patients.

Freezing of gait (FOG) is common in Parkinson's disease and can affect repetitive hand movements. Research [90] explored the impact of auditory cues on controlling these movements in individuals with FOG. While the presence of cues equalized performance between those with and without FOG, their removal led to more unstable and less coordinated movements in FOG patients, while those without FOG maintained control similar to healthy individuals. Study [91] measures and compares visuomotor coordination in probable AD patients and controls using complex tasks. The results show AD patients taking significantly longer to start and perform goal-oriented hand movements, struggling to suppress reflexive eye and hand movements, and utilizing a stepwise instead of anticipatory approach to touch stimuli sequences. Paper [92] explores the impact of PD on eye-hand coordination across tasks of varying cognitive complexity, revealing altered timing and kinematics in visuomotor tasks and slower hand movements in PD patients compared to controls. Study [93] compares the movements of freezers and non-freezers. Results show more significant spatial gait variability in freezers during freezing events. Also, freezers have more prominent upper limb freezing-like events while finger-tapping than non-freezers.

Study [94] evaluates the efficacy of optical hand-tracking techniques for quantifying upper limb bradykinesia in PD. 57 PD patients and the same number of healthy individuals perform tasks including repetitive finger tapping (RFT) and alternating hand movements (AHM). The study analyzes bradykinesia components like velocity, frequency, amplitude, hesitations, and halts and finds significant differences between PD patients and controls. The most notable disparities are velocity and halt duration in RFT and frequency in AHM. Some variables, like frequency and amplitude of RFT, are unreliable due to changes in movement strategy. Alternating forearm movements (AFM) are not considered due to hand recognition issues. Work [95] suggests that bimanual tasks could detect motor cognition impairments in AD due to cognitive system stress. It affirms that difficulties in imitating bimanual, meaningless gestures signify mild to moderate AD and can be evaluated in memory clinic contexts.

Paper [96] explores the clinical aspects of CNS Whipple's disease (WhD) movement abnormalities, focusing on the link between WhD and oculomotor impairments. The study uses two cases to highlight the challenges in detecting and treating these conditions. Study [97] assessed bimanual tapping's role in analyzing tremors in PD and Essential Tremor (ET) patients. Although no intra-group differences were found, PD patients tapped less accurately and with more variability than ET patients and healthy controls. ET subjects also tapped less accurately than healthy controls. Notably, PD patients' tapping accuracy improved when kinetic tremor was recorded with EMG during the task. Report [98] assesses Parkinsonian symptoms through automated hand gesture analysis. It presents a motion capture device and analysis system that records hand/finger movements of control subjects and PD patients. The method successfully differentiates PD patients from controls based on their unique hand/finger motion features.

Relationships also exist between language, leg, eye disorders and abnormal upper limb movements. Paper [99] conducts 20-minute interviews with Wernicke's and Broca's aphasics and non-neurologically impaired subjects to observe hand gestures used in communication. It finds that Broca's aphasics used hand gestures most and non-aphasics least. Certain gesture types were associated more with Broca's aphasics, while both aphasic groups used kinetographs more than the control group. Study [100] assesses arm restlessness in 230 patients with idiopathic restless leg syndrome (RLS), revealing a high incidence. The clinical interview shows that it is typically confined to the fingers and wrist but occasionally extends to the elbow and shoulder.

The following papers suggest that hand gestures indicate pain. Study [101] explores this using qualitative methods, revealing gestures crucially portray pain quality, needing further investigation for better understanding. They're considered beneficial in determining the cause of chest discomfort. Paper [102] studies the usefulness of specific patient gestures in identifying ischemic chest discomfort or myocardial infarction. A prospective observational study with 202 patients observes the Levine Sign, Palm Sign, Arm Sign, and Pointing Sign. However, none of the signs have sensitivities exceeding 38%. The Levine and Arm Signs had specificities between 78-86%, but their positive predictive values are below 55%. The Pointing Sign has a 98% specificity for nonischemic chest discomfort. The study also finds a significant correlation between larger chest pain diameters and evidence of myocardial ischemia. Research [103] examines the frequency and diagnostic accuracy of three hand gestures for chest pain in acute coronary syndrome patients. While 89% of patients use one of these gestures, none accurately indicate this type of pain.

H. ABNORMAL LOWER LIMB MOVEMENTS

RLS is a prevalent neurological movement disorder affecting roughly 10% of the population. Numerous research studies have been conducted on this condition, highlighting its associations with diverse diseases. Paper [104] finds a significant link between Restless Legs Syndrome (RLS) and type 2 diabetes, investigating RLS characteristics and potential risk factors in diabetic patients. Study [105] examines the occurrence of RLS and clinical differences in PD patients. Work [106] examines RLS prevalence in MS patients, using MRI to compare brain and cervical cord damage. Evaluations of 82 MS patients indicate that 30 with RLS have higher EDSS scores, showing its common occurrence in MS. Research [107] identifies a genetic variant tied to frequent limb movements during sleep in RLS patients.

Paper [108] shows celiac disease often accompanies RLS, suggesting it could be a treatable cause for some idiopathic RLS cases. Work [109] examines the impact of frequent sleep leg movement in restless legs syndrome patients, establishing it as an independent predictor of severe left ventricular hypertrophy (LVH). Study [110] assesses the prevalence and severity of primary RLS in temporal lobe epilepsy (TLE) patients, finding it more common and often moderate to severe than in age-matched populations. RLS symptoms were more frequent and slightly severe in the right TLE compared to the left TLE. Paper [111] updates the diagnosis of restless legs syndrome as a standalone condition, reviews its association with PD and other movement disorders, and discusses the role of periodic leg movements (PLMs).

Neurological conditions like Parkinson's disease, dementia, stroke, sclerosis, and others, which might lead to brain damage or disorders, can also result in abnormal movements of the lower limbs. Paper [112] examines the significant link between freezing in Parkinson's syndrome and tachyphemia. Report [113] examines stroke patients and subsequent abnormal involuntary movements (IAMs). Out of 1,500 stroke patients, 56 developed movement disorders within a year. Older patients commonly have chorea; younger ones have dystonia. Surface vascular lesions are common in patients without IAMs, while those with deep lesions are more likely to develop abnormal movements. Work [114] summarizes the epidemiology of falls in stroke patients, noting significant risk factors like balance and gait deficits. Balance issues involve poor postural stability and uncoordinated responses to balance disturbances. Gait problems involve propulsion issues, decreased limb flexion, and reduced stability. Review [115] summarizes recent insights into motor stereotypy disorders in typically developing children, noting their early onset, persistence, high comorbidity with issues like tics, obsessive-compulsive behaviors, and ADHD.

Study [116] studies the frequency of movement issues in Spinocerebellar Ataxias (SCA), evaluating if certain movement disorders typify SCA subtypes. It investigates the role of cerebellar disease, basal ganglia, or other motor components in SCA-related movement issues. Evidence from imaging and neuropathological studies suggests SCAs are often multisystem neurological disorders with degeneration extending beyond the cerebellum. Paper [117] analyzes Leg Stereotypy Syndrome (LSS), which is marked by repetitive leg movement, particularly in seated individuals. The study concludes that LSS frequently occurs in patients with hyperkinetic movement disorders. Study [118] explores the occurrence and clinical impact of dystonic tics (DTs) in Polish GTS patients. It finds DTs are early, common GTS symptoms, often localized to the face, and are more prevalent in those with many tics, contributing to overall tic-related impairment. Paper [119] examines the connection between abnormal movements related to psychosis and several factors, such as the age of symptom onset, duration of untreated psychosis, symptom types, neurocognition, and neurological soft signs. It finds no significant correlation with negative symptom severity, neurocognition, or neurological soft signs.

Alternative causes of abnormal lower limb movements could be damage to the spinal cord, internal organ damage, and pain. Paper [120] discusses three spinal cord injury cases showing Periodic Limb Movements (PLMs) in REM and NREM sleep. Despite a slightly shorter average periodicity of PLMs in REM sleep, its variability was significantly less (3-6 times) than in NREM sleep, indicating more precise periodicity in REM sleep. Study [121] evaluates the prevalence of RLS in patients with end-stage renal disease (ESRD) and determines its association with sleep disorders and premature discontinuation of dialysis. Work [122] investigates the link between periodic limb movements during sleep and heart diseases such as myocardial infarction and cardiovascular and coronary artery disease. It concludes that these sleep movements correlate with increased coronary artery incidences. Paper [123] examines walking kinematics in people with chronic low back pain (CLBP), noting varied hip, knee, and ankle movements in different planes during the stance phase. The study highlights different dominant side hip kinematics in the frontal and transverse planes in the CLBP group compared to healthy individuals.

IV. FINDINGS

This section elaborates on the causational relationships between various diseases and pains and abnormal movements, postures, gestures, and expressions conveyed by the body, including the body (as a whole and trunk), head, neck, shoulders, face, eyes, upper limbs, and lower limbs. The findings are arranged in Tables 1-8 based on the body parts

TABLE 1. Relationships of diseases and pains to *body* postures and movements.

Cite	Disease/Pain	Body Language	Evidence
[17]	Parkinson's disease	Slow and limited body movements, hesitant, slow and reduced facial emotions, unblinking, fixed gaze, stooped and flexed posture, curled up posture, tremors, dyskinesias, dystonia	Strong
[27]	Gilles de la Tourette syndrome	Frequent body movements, twitch movements	Moderate
[28]	Parkinson's disease	Reduced movements and tremors during sleep	Moderate
[29]	Parkinson's disease, Huntington's disease, Gilles de la Tourette syndrome	Rare dyskinesias, tremors during sleep	Strong
[30]	Parkinson's disease	Balance instability during movement with closed eyes	Weak
[31]	Apraxia	Defective finger, hand, and foot gestures	Strong
[32]	Ataxia-Telangiectasia	Unstable postures, slow, involuntary and irregular movements, jerks, tremors	Strong
[33]	Parkinson's disease	Increased lower back rotation and decreased head movement during more significant sideways gaze shifts	Weak
[34]	Coxarthrosis, discopathy, scoliosis, depression, chronic fatigue syndrome	Unbalanced left and right sides of the body poses	Moderate
[35]	Pain	Indicating pain location, demonstrating movements and postures imitating pain	Moderate
[36]	Pain	Arm and leg stretching, finger play, "airplane" pose, seated air pose, salute, tongue extension, hand-to-mouth, leg flexing	Strong
	Stress	Hand-on-face, yawning, hand-to-mouth, flexor actions of legs	
[38]	Pain	Restlessness signs, rubbing, guarding, rigidity, aggression	Strong
		Bracing, decreased mobility, stopping, flinching, pacing, poor posturing	Moderate
[37]	Chronic low back pain	Slumped sitting	Moderate
[115]	Motor stereotypy disorders	Body rocking, head banging, head nodding, thumb sucking, nail/lip biting, hair twirling, handshaking, posturing, flapping, hand waving, hand opening-closing, finger writhing, arm flapping, wrist flexion-extension	Strong

under consideration. The abbreviations used are listed in Table S1.

V. DISCUSSION: ANALYSIS OF ABNORMALITIES

From initially collected 780 papers that mention diseases, pains and their relationships to patients' body motions and postures, we selected 129 papers that clearly discussed the *causational relationships* of diseases and pains to *abnormal body actions* (i.e., abnormal body language elements). The reviews (in Section III) and summaries (in Section IV) are classified based on abnormalities of movements, poses, expressions, and gestures performed by expressible body parts, i.e., trunk (body), head, shoulders, neck, face, eyes, upper limbs, and lower limbs. The review in Section III has focused on extracting useful information about the studied disease/pain and body language correlations from the papers. The tables in Section IV, which describe the causational relationships of the diseases and pains with specific body language elements and their strength levels, offered the first attempt to handle the complexity and unstructuredness issues discussed in Section II. In the following subsections, we provide further insights into the findings and mine different statistical and relational properties using data analysis techniques. To thoroughly study the findings, we first construct the dataset ("∼/md-dataset.csv") based on the tables in Section IV. This dataset consists of 209 rows where each row represents a specific disease/pain-to-body language relation and nine columns that provide all the information related to diseases, pain types, expressible body parts, abnormal body movements, poses, expressions, gestures, relation strength rates, which are extracted from the reviewed papers.

We use descriptive and exploratory data analysis methods, i.e., univariate, bivariate and multivariate analysis techniques, to establish the statistical properties of

TABLE 2. Relationships of diseases and pains to *head* postures and movements.

Cite	Disease/Pain	Body Language	Evidence
[39]	Blow-out fracture	Chin-up, head tilts	Strong
	Brown's syndrome	Face turns, chin elevation, chin depression	
	Double elevator palsy	Chin-up	
	Duane's syndrome	Face turns	
	Inferior oblique palsy	Head tilts	
	Superior oblique palsy	Head tilts, face turns, chin elevation	
	Superior rectus palsy	Chin-up, face turns	
	A-V pattern	Chin elevation	Weak
[40]	Head dyskinesias	Head flopping, head nodding, tics, chorea, myoclonic, irregular eye movements, athetosis, neck hypotonia tremors, dystonia	Strong
[41]	Congenital nystagmus	Head turn	Moderate
[42]	High hyperopia	Chin down	Strong
[43]	Nystagmus	Gaze null, adduction null	Moderate
[44]	A-V pattern strabismus	Face turn, head tilt	Strong
	Brown syndrome	Head tilt, chin up	
	Duane retraction syndrome	Face turn, head tilt	
	Fourth cranial nerve palsy	Head tilt, face turn, chin down	
	Nystagmus blockage syndrome	Head tilt, face turn, chin up	
	Sixth cranial nerve palsy	Face turn, head tilt	
	Thyroid orbitopathy	Chin up, head tilt, face turn	
	Third cranial nerve palsy	Face turn	
	Vertical concomitant deviation	Head tilt, chin up	
	Vertical and horizontal concomitant deviation	Head tilt, face turn, chin up	
[45]	A-V patterns	Chin elevation	Strong
	Dissociated vertical deviation	Head forward tilt	
	Double elevator palsy	Chin-up posture, hypotropia	
	Duane syndrome	Head tilt	
	Inferior oblique palsy	Head tilts face turn, mild hypotropia	
	Muscular torticollis	Head tilt, chin elevation	
	Non-ocular torticollis	Face turn	
	Nystagmus	Face turn, chin elevation, "gaze null," "adducting null" poses	
	Sixth nerve palsy	Face turn	
	Superior oblique palsy	Head tilt, face turn, chin elevation	
	Superior rectus palsy	Head tilt, face turn, chin elevation	
	Third nerve palsy	Face turn	
[46]	Craniomandibular pain	Forward head postures	Weak
[47]	Bobble-head doll syndrome	Partial left abducens palsy, hand tremor, impaired finger-nose movement, tandem walking, hyperactive reflexes, toe extension and abduction	Strong
[48]	Bobble-head doll syndrome	Up and down, side-to-side head movements	Moderate

TABLE 2. *(Continued.)* **Relationships of diseases and pains to *head* postures and movements.**

[49]	Brain tumor	Head tilt	Weak
	Brown's syndrome	Head tilt, chin up, chin down, face turn	Moderate
	Congenital muscular torticollis	Head tilt	Strong
	Duane's syndrome	Face turn	Strong
	Klippel-Feil syndrome	Head tilt, chin up, chin down, face turn	Moderate
	Nystagmus	Face turn, head tilt, chin up, chin down, face turn	Moderate
	Psychomotor delay	Head tilt, chin up, chin down, face turn	Moderate
	Superior oblique muscle palsy	Head tilt	Strong
[51]	Dysarthria in amyotrophic lateral sclerosis	Flaccid, spastic, hyperkinetic movements	Strong
[52]	Huntington's disease	Choreiform movements, bradykinesia, dystonia, tics, myoclonus, rigidity, chorea, ataxia, oculomotor difficulties	Moderate
[53]	Brain tumor	Hemichorea-hemiballism, symptomatic hemidystonia, hemifacial, parkinsonism	Strong
[54]	Whiplash	Flexion, extension, left/right lateral flexion, left/right rotation	Weak
[124]	Bobble-head doll syndrome	Slower rhythmic forward and backward head nodding	Strong
[125]	Nystagmus	Head turn, head tilt, chin up and chin down	Strong
[50]	Thoracic kyphosis	Forward head posture	Strong
[126]	Tissue mechanosensitivity	Forward head posture	Weak
[127]	Pain	Head movements and postures	Moderate

TABLE 3. **Relationships of diseases and pains to *neck* postures and movements.**

Cite	Disease/Pain	Body Language	Evidence
[55]	Ankylosing spondylitis	Limited flexion/extension/rotation, left/right lateral flexion	Moderate
[56]	Cervical dystonia	Limited right/left rotation, slow flexion/extension	Moderate
[57]	Parkinson's disease	Camptocormia, antecollis, retrocollis, Pisa syndrome, scoliosis	Strong
[58]	Parkinson's disease	Retrocollis	Moderate
[59]	Neck pain	Excessive forward head posture	Moderate
[60]	Neck pain	Forward head posture, side flexion, head extension, head rotation	Weak
[61]	Neck pain	Reduced forward neck posture, neck flexor and neck extensor	Strong
[62]	Chronic neck pain	Altered head and neck postures	Strong
[63]	Chronic neck pain	Reduced flexion/extension, bilateral lateral flexion and rotation	Moderate
[64]	Neck pain	Increased forward head posture	Moderate
[128]	Grisel's syndrome	Severe neck stiffness, trismus	Weak

diseases, pains, expressible body parts, and body language, as well as the properties of disease/pain-to-body language and body language-to-disease/pain causational relationships. As a result, we obtain the complete and accurate list of body language elements caused by a specific disease and pain, and vice versa, the comprehensive list of diseases and pains causing a specific body language element.

We should also mention that the current analysis is subjective to the information provided in the reviewed papers, which still needs to be completed yet. However, the used approaches and developed analysis methods and techniques in the research are applicable and scalable to any extent. We should focus on a specific disease or body language and thoroughly investigate using these methods and techniques to obtain more complete and accurate results.

A. STATISTICAL PROPERTIES OF DISEASES, PAINS AND BODY LANGUAGE

The preliminary observation of the findings reveals that the reviewed papers study the effect of 86 diseases and pains on

TABLE 4. Relationships of diseases and pains to *shoulder* postures and movements.

Cite	Disease/Pain	Body Language	Evidence
[65]	Parkinson's disease	Frozen shoulder, restricted shoulder movements	Strong
[129]	Parkinson's disease	Increased thoracic kyphosis, decreased trunk mobility, reduced shoulder movements, rigidity, postural alterations	Strong
[130]	Frozen shoulder	Severe loss of shoulder rotations	Strong
[50]	Thoracic kyphosis	Rounded/forward shoulder postures	Moderate
[131]	Cervical pain dysfunction syndromes	Head protraction-retraction, shoulder protraction-retraction	Weak

TABLE 5. Relationships of diseases and pains to *facial* expressions.

Cite	Disease/Pain	Body Language	Evidence
[132]	Parkinson's disease	Reduced smiling facial features	Strong
[133]	Schizophrenia	Reduced facial expressions for happiness, sadness, fear, anger, surprise, and disgust	Strong
[134]	Schizophrenia, depression	Reduced emotional expressions: impaired posed and spontaneous expression, less smiling, fewer gestures	Strong
[135]	Dementia	Intensive and frequent facial pain expressions	Strong
[136]	Parkinson's disease	Decreased lip and jaw movements	Strong
[66]	Pain	In children: brow lowering, closed eyes, deepened nasolabial cleft, varied mouth opening, taut cupping In adults: brow furrowing, eyes closing, lid tightening, eye narrowing, cheek raising, upper lip lifting, nasolabial fold, lip and mouth opening	Strong
[67]	Chest pain	Brow lowering, lip pressing, lip parting, head-turning	Strong
[68]	Pain	In neonates: brow bulging, eye squeezing, nasolabial furrow, vertical mouth stretching, lip corner pulling, chin tremor In children: eye squeezing, eye squinting, cheek raising, node wrinkling, nasolabial furrow, upper lip raising, horizontal/vertical mouth stretching, flared nostril In adults: brow furrowing, lid tightening, cheek raising, nose wrinkling, upper lip raising, eyes closing, lip corner pulling, horizontal mouth stretching In the elderly: lid tightening, cheek lifting, nose wrinkling, lip raising, corner of the lip pulling	Strong
[69]	Clinical pain	Brow lowering, orbital muscle tightening, nose-wrinkling, lip raising, eye closing	Strong
[70]	Pain	Brow lowering, cheek raising, upper-lip raising, eye closing	Moderate
[137]	Brain damage	Reduced facial expressions	Weak
[138]	Schizophrenia	Reduced facial expressions	Strong
[139]	Brain damage	Reduced facial expressions	Weak

eight different body parts, causing abnormalities in the poses, movements, gestures and expressions. The distribution of the papers studying the diseases/pains causing abnormalities in each body part is depicted in Table 9.

It is observable that the count of papers reviewed (**129**) does not match the aggregate quantity (**206**) presented in Table 9. This difference is attributed to the fact that a single paper might examine the impact of a particular disease or pain on multiple body parts, or alternatively, it could explore the effects of several diseases on a single body part.

For instance, paper [115] investigates the impact of motor stereotypy disorders on the posture and movement of the body and head, along with gestures of the upper limbs. Another paper [47] delves into the symptoms and signs of bobblehead

TABLE 6. Relationships of diseases and pains to *eye* movements.

Cite	Disease/Pain	Body Language	Evidence
[71]	Parkinson's disease	Rapid eye movements	Strong
[72]	Alzheimer's disease	Normal fixation, increased intrusive saccades	Strong
[73]	Parkinson's disease	Reduced voluntary saccade latency	Strong
	Dementia	Reduced reflexive and voluntary saccades, increased antisaccade mistakes	
	Dementia with Lewy bodies	Increased/decreased saccades latency, increased antisaccades	
	Huntington's disease	Reduced saccade speed and accuracy, impaired smooth pursuit, increased errors in antisaccades and memory-guided saccades, heightened distractibility	
	Dementia	Antisaccade errors	
	Alzheimer's disease	Increased fixation instability, delayed reflexive and voluntary saccade latency, elevated antisaccade errors, reduced correction of antisaccade errors	
[74]	Schizophrenia	Damaged smooth pursuit eye movements	Strong
[75]	Parkinson's disease	More numbers, slower eye movements while turning	Weak
[76]	Parkinson's disease	Altered latency, amplitude, velocity and gain of saccades	Strong
[77]	Alzheimer's disease	Slow, latent, inaccurate prosaccades, incorrect, latent anti-saccades, saccadic intrusions, altered fixational eye movements, inaccurate latent smooth pursuit	Strong
[78]	Parkinson's disease	Increased latency, decreased gain, decreased precision in horizontal and vertical saccades, increased multistep of vertical saccades, increased latency and errors of antisaccades	Strong
[140]	Alzheimer's disease	Spontaneous eye movements: increased latency in reflexive saccades (horizontal and vertical), reduced velocity in vertical saccades, reduced gain in unpredictable saccades Antisaccades: lower antisaccade rate, increased latency, higher reflexive error rate, lack of self-correction Reflexive antisaccades: higher latency variability, preserved gap, simultaneous or overlap effects Fixation: higher saccadic intrusion occurrence Pursuit: reduced gain and velocity, increased catch-up saccade and saccadic intrusion occurrence, higher anticipatory saccade amplitude Blinks: higher occurrence during fixation, deficit eye blinks	Strong
[141]	Alzheimer's disease	Increased saccadic length, uncorrected antisaccades rise	Strong
[142]	Creutzfeldt-Jakob disease	Periodic alternating nystagmus, alternating gaze deviations, slow upward saccades (early stages), saccade loss	strong
[143]	Parkinson's disease	Hypometric/multistep saccades, delayed saccades, variable saccades, smooth pursuit	Strong
	Huntington's disease	Saccadic intrusion, fixation impairment, slowed saccades, impaired pursuit	
	Multiple sclerosis	Internuclear ophthalmoplegia, nystagmus, impaired pursuit	
[144]	Wilson's disease	Slow saccades	Strong

doll syndrome, manifested through abnormal eye movements and unusual gestures in patients' upper and lower limbs. Conversely, paper [49] explores the potential causative relationships between eight specific diseases and abnormal head postures and movements.

Figure 3 provides a more detailed depiction of the distribution of the surveyed papers in relation to the body parts and also displays the proportion of diseases and pains.

Since our primary focus is to establish the causative relations between diseases/pains and abnormal body actions,

TABLE 7. Relationships of diseases and pains to *upper limb* movements.

Cite	Disease/Pain	Body Language	Evidence
[79]	Tuberculous meningitis	Tremors, chorea, dystonia	Strong
[80]	Limb Apraxia	Frequency and severity errors in intransitive limb gestures	Strong
[82]	Ataxia-telangiectasia	Tremor, dystonia, athetosis, dystonic jerks, myoclonus	Strong
[84]	Multiple sclerosis	Impaired coordination, slow hand movements, prolonged touch duration	Strong
[85]	Parkinson's disease	Slow-starting repetitive hand movements, random forward/backward, left/right-hand movements	Moderate
[86]	Parkinson's disease	Slow finger tapping, hand opening-closing, forearm rotation	Strong
[87]	Parkinson's disease	Slow finger movements with reduced amplitude	Strong
[88]	Parkinson's disease	Slower hand movements with extended latency, duration, and reduced amplitude	Moderate
[89]	Parkinson's disease	Reduced amplitude, increased frequency of index finger flexion	Moderate
[90]	Parkinson's disease with freezing of gait	Reduced finger stability, faster and erratic movements, decreased coordination	Strong
[91]	Alzheimer's disease	Reduced goal-directed hand movements, decreased hand movements	Strong
[92]	Parkinson's disease	Slow hand movements	Strong
[94]	Parkinson's disease	Reduced finger tapping, slow hand movements with less force and pauses	Moderate
[95]	Alzheimer's disease	Imitate bimanual, meaningless hand gestures	Strong
[97]	Parkinson's disease, essential tremor	Less accurate and more variable bimanual tapping in PD than essential tremor patients	Strong
[98]	Parkinson's disease	Hand and finger bradykinesia and tremors	Strong
[99]	Aphasia	Spontaneous illustrative gestures	Strong
[100]	Restless leg syndrome	Arm tingling or sensations	Strong
[101]	Pain	Co-speech gestures	Moderate
[102]	Chest discomfort	Levine's sign (fist to chest), palm sign (hand to chest), arm sign (touching left arm) for nonischemic chest discomfort, pointing sign (finger pointing)	Moderate
[103]	Chest pain	Levine's sign (clenched fist), extended hand, hands moving outward from the center	Strong
[93]	Parkinson's disease with freezing of gait	Variable finger tapping and hand diadocho-kinetic movements characterized by rapid and varied muscle movements	Strong
[96]	Whipple disease	Pendular nystagmus, vertical nystagmus, spontaneous movements (myorhythmia and myoclonus), ataxia	Moderate

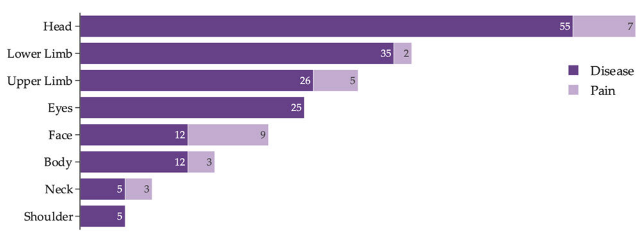

FIGURE 3. The distribution of the reviewed papers concerning body parts.

it is crucial first to determine the impacts of diseases and pains on the specific body parts where these abnormalities occur. The analysis of the tables in the previous section yields Figure 4, representing the distribution of various diseases and pains across the body parts under consideration. In the figure, to ensure accuracy, we only include those diseases and pains mentioned in a minimum of three articles. Table S2 shows the complete list of diseases and pains.

Figure 4 illustrates the high popularity of certain diseases and pains, including Parkinson's disease, various types of pains, and bobblehead doll syndrome, in terms of the number and range of affected body parts. Of particular note is Parkinson's disease, which induces abnormalities in movements,

TABLE 8. Relationships of diseases and pains to *lower limb* movements.

Cite	Disease/Pain	Body Language	Evidence
[104]	Type 2 diabetes	Restless leg movements	Moderate
[105]	Parkinson's disease	Restless leg movements	Moderate
[106]	Multiple sclerosis	Restless leg movements	Strong
[107]	Restless leg syndrome	Periodic limb movements during sleep	Moderate
[108]	Celiac disease	Restless leg movements	Moderate
[109]	Left ventricular hypertrophy	Frequent leg movement during sleep	Strong
[110]	Epilepsy	Restless leg movements	Strong
[111]	Movement disorders	Restless leg movements, periodic leg movements	Strong
[112]	Parkinsonian syndromes	Lower limb freezing	Strong
[113]	Post-stroke movement disorders	Chorea, dystonia, tremor, parkinsonism	Strong
[114]	Stroke	Falling, balance issues, knee flexion	Strong
[116]	Spinocerebellar ataxias	Myoclonus, dystonia, chorea, parkinsonism, tremor	Strong
[117]	Leg stereotypy syndrome	Involuntary, repetitive, rhythmic and continuous leg movements while sitting, swaying movements of the legs and trunk while standing	Strong
[118]	Gilles de la Tourette syndrome	Dystonic tics: twisting, pulling, squeezing movements	Strong
[119]	Noneffective psychosis	Dyskinesias (involuntary), stereotypies (voluntary and repetitive), catatonic-like signs (hypokinetic and negativistic)	Weak
[121]	End-stage renal disease	Restless leg movements	Moderate
[122]	Cardiovascular diseases	Periodic limb movements during sleep	Moderate
[123]	Chronic low back pain	Lower limb altered movements	Strong
[93]	Parkinson's disease with freezing of gait	High variable walking	Strong
[145]	Autosomal dominant cerebellar ataxias	Parkinsonism, dystonia, chorea, myoclonus, akathisia, PND	Strong
[146]	Cerebrovascular disease	Parkinsonism, chorea, ballism, athetosis, dystonia, tremor, myoclonus, asterixis, stereotypies, akathisia, tics	Strong
[147]	Hemodialysis with restless legs syndrome	Repetitive, purposeless leg movements during sleep	Moderate
[148]	Leg stereotypy syndrome	Repetitive, patterned leg movements (stereotypy), slow tremor	Moderate
[149]	Restless legs syndrome	Unpleasant sensations: "need to move," "crawling," "tingling," "restless," "cramping," "creeping," "pulling," "painful," "electric," "tension," "itching," "burning," "prickly"	Weak
[150]	Mirtazapine-associated movement disorders	Restless leg movements, tremors	Strong
		Akathisia, periodic limb movement disorders, dystonia	Moderate
		Dyskinesia, parkinsonism, tics	Weak
[151]	Narcolepsy	High frequent periodic leg movements	Strong
[152]	PMD	Movement disorders, tremors, gait disorders, PMDs in children	Moderate
[153]	Sleep-related movements	Hypnic jerks, exploding head syndrome, propriospinal myoclonus, epileptic myoclonus, benign sleep myoclonus of infancy, bruxism, nocturnal leg cramps, rhythmic movements, hypnagogic foot tremor, periodic limb movements, body rocking, juxta capita, epileptic seizures	Strong
[154]	Stroke	Balance disability	Strong
[155]	Whipple's disease	Limb myorhythmia	Moderate

TABLE 9. The distribution of the papers studied the causational relationships of diseases/pains to body language.

	body	head	neck	shoulder	face	eye	upper limb	lower limb	total
disease/pain	16	62	8	5	21	25	30	39	**206**

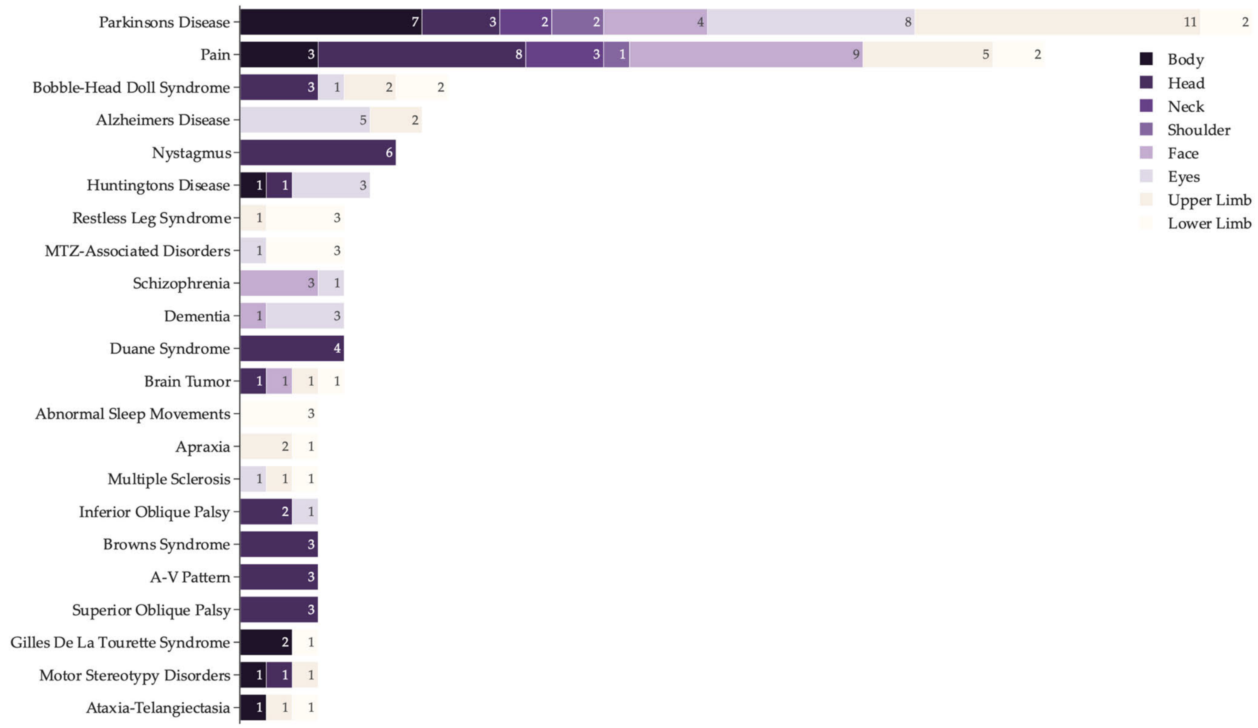

FIGURE 4. The distribution of the disease and pains across different body parts as found in at least three papers.

TABLE 10. The lists of abnormal body actions taking place in different body parts.

Body part	Abnormal body actions
Body	Body bending, body contraction, body rigidity, body writhing, irregular movement, reduced movement, slow movement, sudden movement, tremor, unbalanced pose
Head	Chin down, chin up, head backward bent, head contraction, head forward bent, head jerk, head nodding, head shaking, head side bent, head tilt, head turn, irregular movement
Neck	Irregular neck pose, reduced backward bent, reduced forward bent, reduced neck turn, reduced rotation
Shoulder	Forward pose, frozen shoulder, protraction-retraction, reduced movement, rounded pose, shoulder rigidity
Face	Irregular expression, pain expression, reduced expression
Eyes	Incorrect antisaccade, incorrect saccade, irregular movement, latent saccade, saccadic intrusion, slow saccade, eye impairment, unstable saccade
Upper limb	Arm contraction, arm pointing, defective finger movement, defective hand movement, finger pointing, frequent finger movement, hand jerk, hand pointing, hand rigidity, hand tremor, irregular movement, reduced finger movement, reduced hand movement, repetitive movement, slow arm movement, slow finger movement, slow hand movement, sudden hand movement
Lower limb	Frequent movement, involuntary movement, leg contraction, leg freezing, leg jerk, leg rigidity, leg sign, leg tremor, leg twitching, leg writhing, periodic movement, repetitive movement, restless leg movement, slow leg movement, unstable movement

postures, gestures, and facial expressions throughout the body. For other diseases, there appears to be a near-even distribution in the number and diversity of body parts impacted. Notably, the head (36), eyes (24), upper limb (26), and lower limb (19) are most frequently affected by the diseases and pains under consideration.

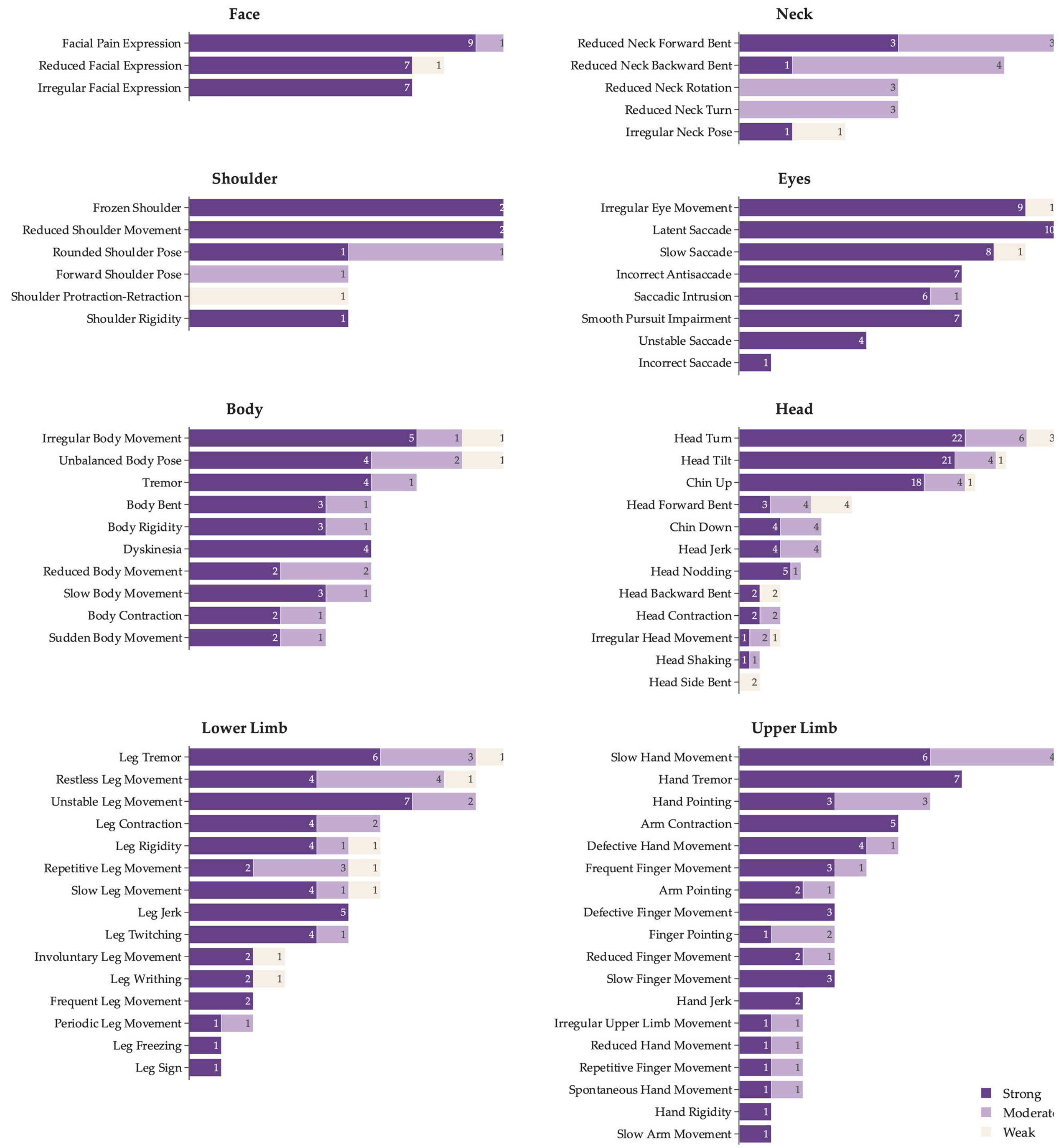

FIGURE 5. The list of abnormal body language elements in each body part and the distributions of the strength levels of the established evidence mapped to the color intensities.

The most crucial information in the following subsection is the list of all abnormal body language (ABL) elements and abnormalities resulting from the diseases and pains discussed in the papers and the distributions of the ABL elements, including the strength rates. We first give the lists of all the distinct ABL elements for each body part in Table 10. In the table, we can notice that the upper limbs, lower limbs, head, and body have many abnormalities related to postures and movements.

The following subsection outlines the array of abnormal physical responses and irregularities resulting from the various illnesses and discomforts discussed in the articles, along

TABLE 11. The lists of abnormality patterns according to the body parts.

face	eyes	neck	shoulders
irregularity	incorrectness	irregularity	roundedness
pain	irregularity	reduction	freezing
reduction	latency		bend
	intrusion		reduction
	slowness		rigidity
	impairment		
	instability		

body	head	upper limbs	lower limbs
bend	turn	contraction	frequency
contraction	irregularity	sign	involuntariness
rigidity	contraction	defectiveness	contraction
writhing	bend	frequency	freezing
irregularity	jerk	jerk	jerk
reduction	repetitiveness	rigidity	rigidity
slowness	tremor	tremor	sign
suddenness		irregularity	tremor
tremor		reduction	twitching
instability		repetitiveness	writhing
		slowness	repetitiveness
		suddenness	restlessness
			slowness
			instability

TABLE 12. The mapping of diseases and pains to abnormal *body* movements and poses.

Diseases	Abnormal body actions
Gilles de la Tourette syndrome, Parkinson's disease, oncology	body contraction
Parkinson's disease, chronic low back pain	body forward bent
Pain in older people with cognitive impairment, ataxia-telangiectasia, Gilles de la Tourette syndrome, Parkinson's disease, motor stereotypy disorders	irregular body movement
Parkinson's disease, pain in older people with cognitive impairment	reduced body movement
Pain in older people with cognitive impairment, Parkinson's disease, oncology	body rigidity
Parkinson's disease, pain in older people with cognitive impairment, ataxia-telangiectasia, oncology	slow body movement
Ataxia-telangiectasia, oncology, pain in older people with cognitive impairment	sudden body movement
Parkinson's disease, pain in older people with cognitive impairment, oncology, ataxia-telangiectasia, scoliosis	unbalanced body pose
Parkinson's disease, oncology	body writhing
Parkinson's disease, Huntington's disease, ataxia-telangiectasia, Gilles de la Tourette syndrome, oncology	tremor

with their distribution patterns and intensity rates. We initially provide a comprehensive inventory of distinct abnormal bodily movements associated with each body part, as presented in Table 10. Upon reviewing the table, it becomes evident that many abnormalities in postures and movements are associated with the upper limbs, lower limbs, head, and body.

Figure 5 continues to put more clarity into the strength levels of the abnormal body actions happening in all the expressible body parts caused by diseases and pains. The

TABLE 13. The mapping of diseases and pains to abnormal *head* movements and poses.

Diseases	Abnormal body actions
Brown's syndrome, Klippel-Feil syndrome, psychomotor delay, nystagmus, high hyperopia, fourth cranial nerve palsy	chin down
Superior rectus palsy, superior oblique palsy, nystagmus, muscular torticollis, A-V pattern, browns syndrome, psychomotor delay, horizontal concomitant deviation, thyroid orbitopathy, vertical concomitant deviation, Klippel Feil syndrome, Parkinson's disease, double elevator palsy, blow-out fracture	chin up
Neck pain, Parkinson's disease, head dyskinesias, whiplash	head backward bent
Head dyskinesias, Huntington's disease	head contraction
Neck pain, motor stereotypy disorders, pain, tissue mechanosensitivity, thoracic kyphosis, Parkinson's disease, craniomandibular pain, whiplash	head forward bent
Huntington's disease, head dyskinesias	head jerk
Motor stereotypy disorders, head dyskinesias, Parkinson's disease, bobble-head doll syndrome	head nodding
Neck pain, chronic neck pain, Huntington's disease	irregular head movement
Bobble-head doll syndrome, head dyskinesias	head shaking
Whiplash	head side bent
Brain tumor, browns syndrome, superior oblique palsy, blow-out fracture, A-V pattern, sixth nerve palsy, thyroid orbitopathy, psychomotor delay, Duane syndrome, inferior oblique palsy, congenital muscular torticollis, vertical concomitant deviation, Klippel Feil syndrome, muscular torticollis, nystagmus, horizontal concomitant deviation, fourth cranial nerve palsy, superior rectus palsy	head tilt
Psychomotor delay, superior oblique palsy, inferior oblique palsy, Klippel Feil syndrome, nystagmus, sixth nerve palsy, non-ocular torticollis, A-V pattern, superior rectus palsy, vertical concomitant deviation, horizontal concomitant deviation, thyroid orbitopathy, fourth cranial nerve palsy, browns syndrome, Duane syndrome, third nerve palsy, neck pain, chest pain, whiplash, Parkinson's disease	head turn

TABLE 14. The mapping of diseases and pains to abnormal *neck* movements and poses.

Diseases	Abnormal body actions
Chronic neck pain, Grisel's syndrome	irregular neck pose
Ankylosing spondylitis, neck pain, chronic neck pain, cervical dystonia, Parkinson's disease	reduced neck backward bent
Parkinson's disease, chronic neck pain, ankylosing spondylitis, neck pain, cervical dystonia	reduced neck forward bent
Chronic neck pain, ankylosing spondylitis, cervical dystonia	reduced neck rotation
Ankylosing spondylitis, chronic neck pain, cervical dystonia	reduced neck turn

TABLE 15. The mapping of diseases and pains to abnormal *shoulder* movements and poses.

Diseases	Abnormal body actions
Thoracic kyphosis, Parkinson's disease	rounded shoulder pose
Frozen shoulder, Parkinson's disease	frozen shoulder
Parkinson's disease	reduced shoulder movement
Parkinson's disease	shoulder rigidity
Cervical pain dysfunction syndromes	shoulder protraction-retraction

figure demonstrates that the eyes have the strongest evidence for disease/pain-to-body language correlations, while the studies on abnormal neck movements and postures do not intensely support the correlations in the numbers of the papers that studied these correlations and the strengths of their evidence.

TABLE 16. The mapping of diseases and pains to abnormal *facial* expressions.

Diseases	Abnormal body actions
Brain tumor, Parkinson's disease, dementia	irregular facial expression
Chest pain, clinical pain, pain, pain in elderly	facial pain expression
Brain damage, Parkinson's disease, depression, schizophrenia	reduced facial expression

TABLE 17. The mapping of diseases and pains to abnormal *eye* movements.

Diseases	Abnormal body actions
Alzheimer's disease, Huntington's disease, dementia, Parkinson's disease	incorrect antisaccade
Parkinson's disease	incorrect saccade
Alzheimer's disease, bobble-head doll syndrome, inferior oblique palsy, multiple sclerosis, Parkinson's disease, Creutzfeldt-Jakob disease, mirtazapine-associated movement disorders	irregular eye movement
Dementia, Alzheimer's disease, Parkinson's disease, Huntington's disease	latent saccade
Parkinson's disease, Huntington's disease, Alzheimer's disease	saccadic intrusion
Dementia, Parkinson's disease, Alzheimer's disease, Huntington's disease, Wilsons disease, Creutzfeldt-Jakob disease	slow saccade
Creutzfeldt-Jakob disease, bobble-head doll syndrome, Alzheimer's disease, schizophrenia, Huntington's disease, multiple sclerosis, Parkinson's disease	smooth pursuit impairment
Creutzfeldt-Jakob disease, Parkinson's disease	unstable saccade

TABLE 18. The mapping of diseases and pains to abnormal *upper limb* movements.

Diseases	Abnormal body actions
Restless leg syndrome, Parkinson's disease, tuberculous meningitis	arm contraction
Pain	arm pointing
Bobble-head doll syndrome, apraxia	defective finger movement
Alzheimer's disease, multiple sclerosis, apraxia, Parkinson's disease	defective hand movement
Pain	finger pointing
Parkinson's disease	frequent finger movement
Tuberculous meningitis, ataxia-telangiectasia	hand jerk
Pain, stress	hand pointing
Brain tumor	hand rigidity
Parkinson's disease, tuberculous meningitis, brain tumor, bobble-head doll syndrome, ataxia-telangiectasia	hand tremor
Brain tumor, Parkinson's disease	irregular upper limb movement
Parkinson's disease	reduced finger movement
Alzheimer's disease, Parkinson's disease	reduced hand movement
Parkinson's disease	repetitive finger movement
Parkinson's disease	slow arm movement
Parkinson's disease	slow finger movement
Motor stereotypy disorders, Parkinson's disease, ataxia-telangiectasia, Alzheimer's disease, brain tumor	slow hand movement
Aphasia, Whipple's disease	spontaneous hand movement

Though abnormal activities, i.e., movements, poses, gestures and expressions, can appear in different body parts with specific characteristics, they share the same, or at least similar, abnormalities. For instance, tremors or jerks can happen

TABLE 19. The mapping of diseases and pains to abnormal *lower limb* movements.

Diseases	Abnormal body actions
Narcolepsy, left ventricular hypertrophy	frequent leg movement
Brain tumor, noneffective psychosis, cerebrovascular disease	involuntary leg movement
Mirtazapine-associated movement disorders, post-stroke movement disorders, psychogenic movement disorders, sleep disorders, cerebrovascular disease, spinocerebellar ataxias	leg contraction
Parkinsonian syndromes	leg freezing
Post-stroke movement disorders, abnormal sleep movements, spinocerebellar ataxias, ataxia-telangiectasia, cerebrovascular disease	leg jerk
Cerebrovascular disease, mirtazapine-associated movement disorders, psychogenic movement disorders, post-stroke movement disorders, brain tumor, spinocerebellar ataxias	leg rigidity
General pain	leg sign
Mirtazapine-associated movement disorders, spinocerebellar ataxias, brain tumors, post-stroke movement disorders, cerebrovascular disease, psychogenic movement disorders, leg stereotypy syndrome, sleep disorders	leg tremor
Spinocerebellar ataxias, sleep disorders, psychogenic movement disorders, cerebrovascular disease, brain tumor	leg twitching
Gilles de la Tourette syndrome, mirtazapine-associated movement disorders, cerebrovascular disease	leg writhing
Sleep disorders, restless leg syndrome, mirtazapine-associated movement disorders	periodic leg movement
Noneffective psychosis, restless leg syndrome, leg stereotypy syndrome, Whipple's disease, sleep disorders	repetitive leg movement
End-stage renal disease, epilepsy, Parkinson's disease, restless leg syndrome, type 2 diabetes, multiple sclerosis, movement disorders, mirtazapine-associated movement disorders, celiac disease	restless leg movement
Psychogenic movement disorders, spinocerebellar ataxias, mirtazapine-associated movement disorders, post-stroke movement disorders, cerebrovascular disease, brain tumor, noneffective psychosis, sleep disorders	slow leg movement
Brain tumor, bobble-head doll syndrome, psychogenic movement disorders, cerebrovascular disease, Parkinson's disease, mirtazapine-associated movement disorders, stroke	unstable leg movement

TABLE 20. The selected ABL elements for Parkinson's disease where the CSIs are greater than 0.5.

Selected Abnormal Body Actions for Parkinson's Disease		
body forward bent	irregular facial expression	frequent finger movement
irregular body movement	reduced facial expression	hand tremor
reduced body movement	irregular eye movement	reduced finger movement
unbalanced body pose	latent saccade	repetitive finger movement
reduced shoulder movement	slow saccade	slow finger movement
rounded shoulder pose	unstable saccade	slow hand movement

in the body (trunk), head, hands, and legs; slow, reduced, repetitive, frequent, involuntary movements are specific to the upper limbs, lower limbs, head, eyes, and face. Thus, we can extract these *abnormality patterns* from all the abnormal body activities (see Table 11).

The observation of Table 11 reveals 27 different abnormality patterns of movements, postures, gestures and expressions in different body parts.

B. RELATIONAL PROPERTIES OF DISEASES, PAINS AND BODY LANGUAGE

The previous subsection provides a deep and accurate understanding of the individual descriptive properties of the dataset's features, i.e., the body parts, diseases, pains, and abnormal body language elements (postures, movements, gestures, and expressions) resulting from the effects of the diseases and pains. This subsection focuses on establishing

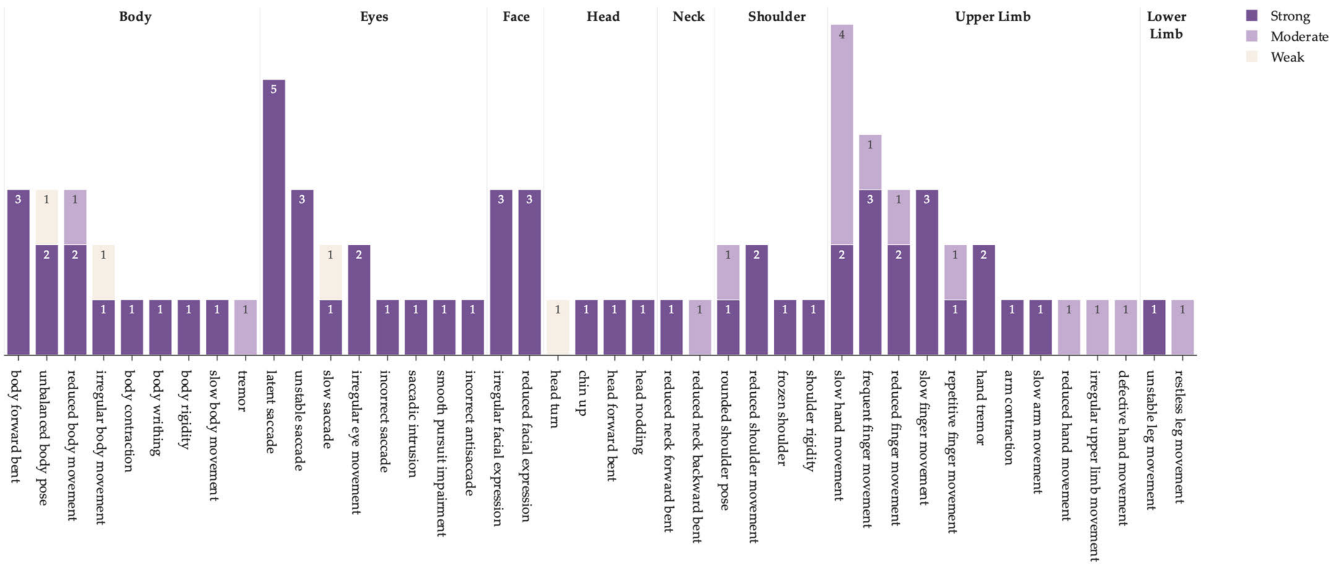

FIGURE 6. The abnormal body language elements caused by Parkinson's disease.

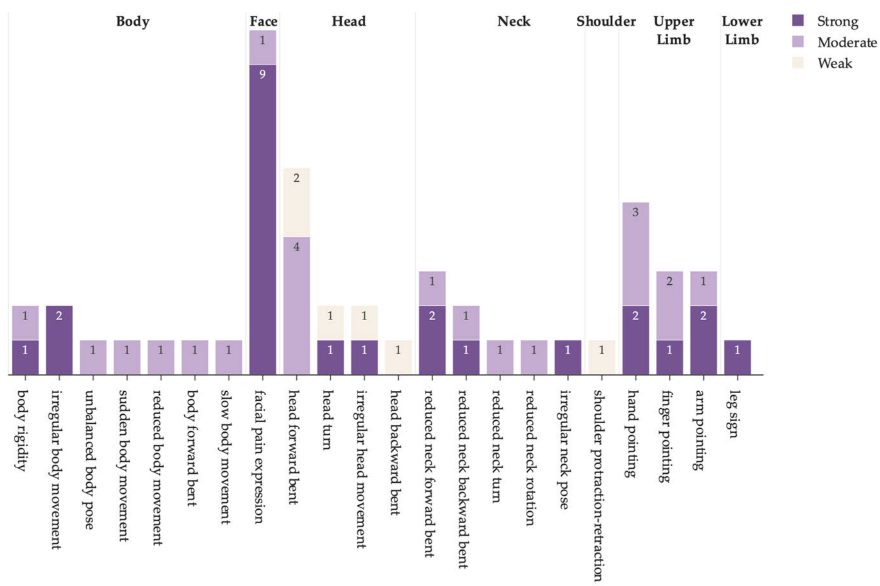

FIGURE 7. The abnormal body language elements caused by different pains.

the causational relationships of diseases and pains with ABL elements and identifying the comprehensive and accurate lists of ABL elements caused by diseases and pains and the lists of diseases and pains causing specific ABL elements. Tables 12-19 describe the causational relationships of diseases and pains with ABL elements.

The "mapping tables" above provide all **disease/pain-to-abnormal body actions'** causational relationships established in the reviewed papers. These tables can extract the *complete* lists of all the abnormal body actions for each corresponding disease or pain. However, these lists are not *reliable* yet since not all causational relationships established or discussed in the papers have strong support from the conducted studies. Thus, to determine the *complete* and *accurate* (trustworthy) list of abnormal body actions for a specific disease or pain, we must also consider the strength rates of the relationships. Since the reviewed papers discuss 86 diseases and pains, considering the causational relationships for each disease or pain is lengthy and tedious.

Moreover, from Table 9 and Figure 4, we can also observe that the correlation problems have been studied in detail for only a few diseases and pains in the reviewed literature, which may result in incomplete and unreliable lists of abnormal

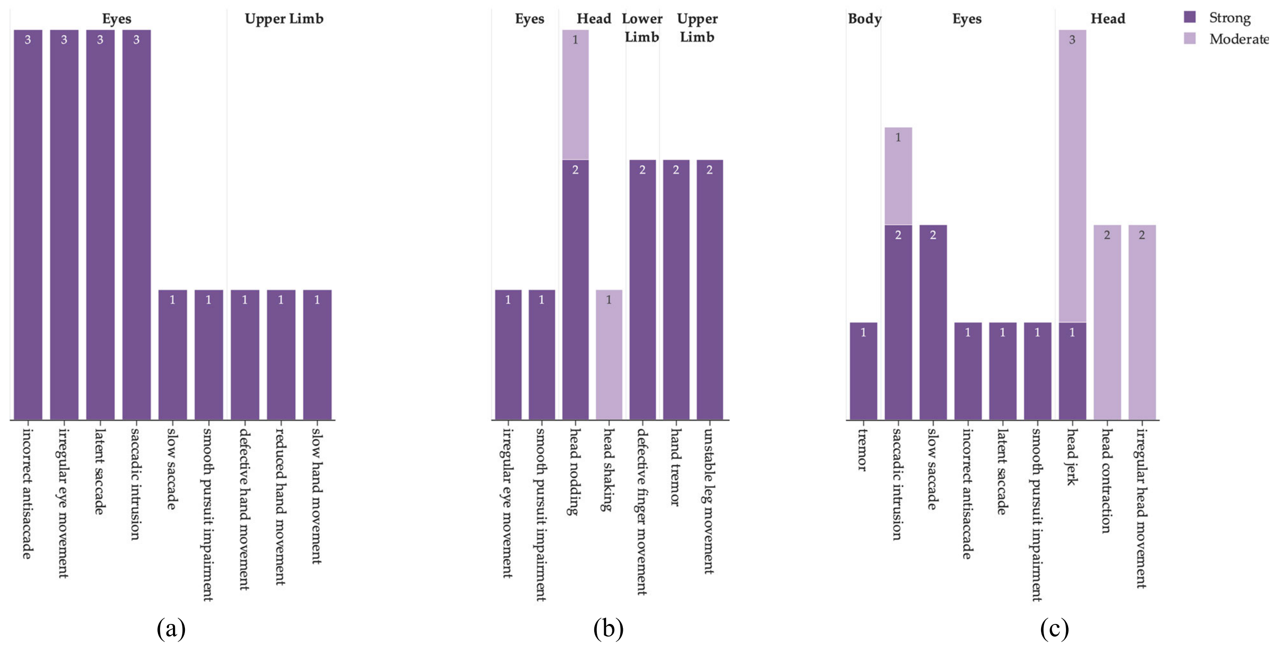

FIGURE 8. The abnormal body language elements caused by (a) Alzheimer's disease, (b) bobblehead doll syndrome and (c) Huntington's disease.

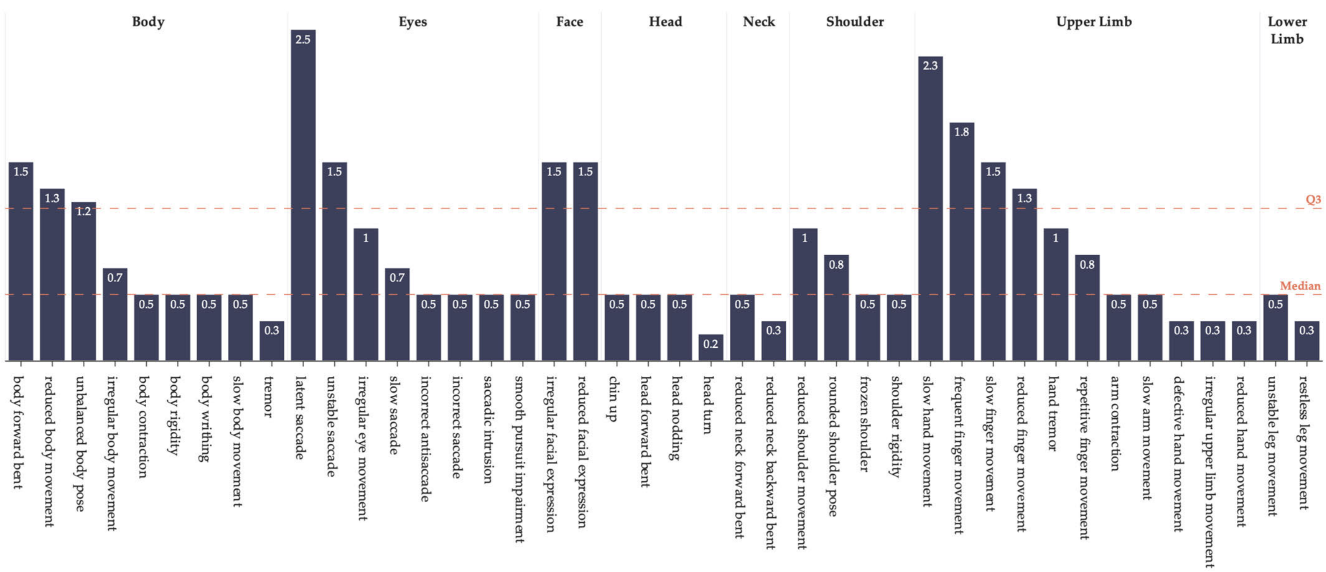

FIGURE 9. The CSI values for Parkinson's disease and the correlated ABL elements.

body actions for diseases and pains. Hence, we continue our research on the causational relationships of "top-five conditions," i.e., Parkinson's, Huntington's, Alzheimer's diseases, bobblehead doll syndrome, and pain (i.e., all pain cases are considered together). Figures 6-8 illustrate the abnormal body language elements with corresponding strength levels caused by these diseases (the precise details can be found in Tables S3-S7).

As the papers consider three levels of strength evidence ("strong," "moderate," and "weak") for the correlations, we need to aggregate different strength levels for each disease/pain-to-abnormal body action relationship to obtain a unified correlation strength measurement, which we call *correlation strength index*, for selecting the final complete and accurate list of abnormal body actions for a specific disease or pain.

Thus, for each disease and pain above, we define and analyze its *correlation strength index (CSI)* with each body language element resulting from this disease/pain. When we define the correlation strength index for a relationship,

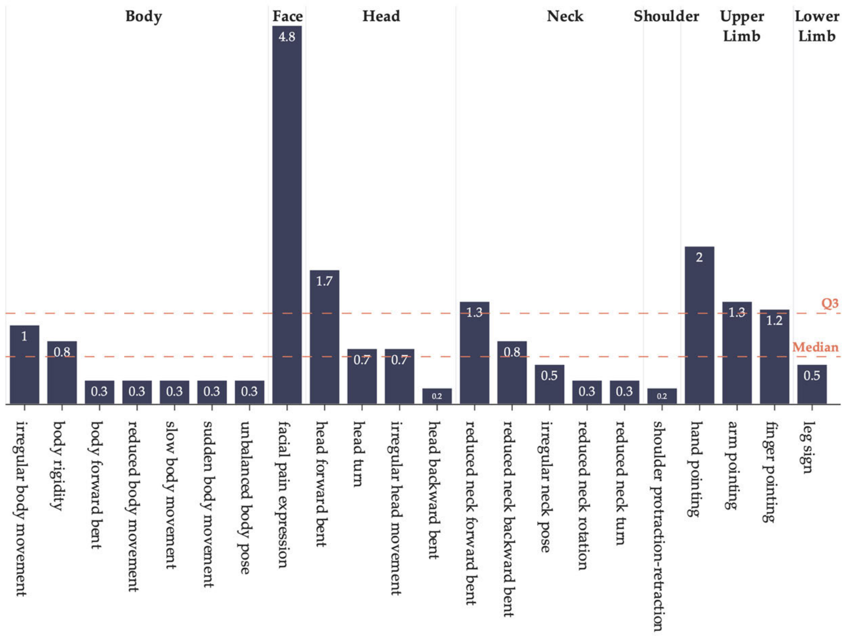

FIGURE 10. CSI values for pains and the correlated abnormal body actions.

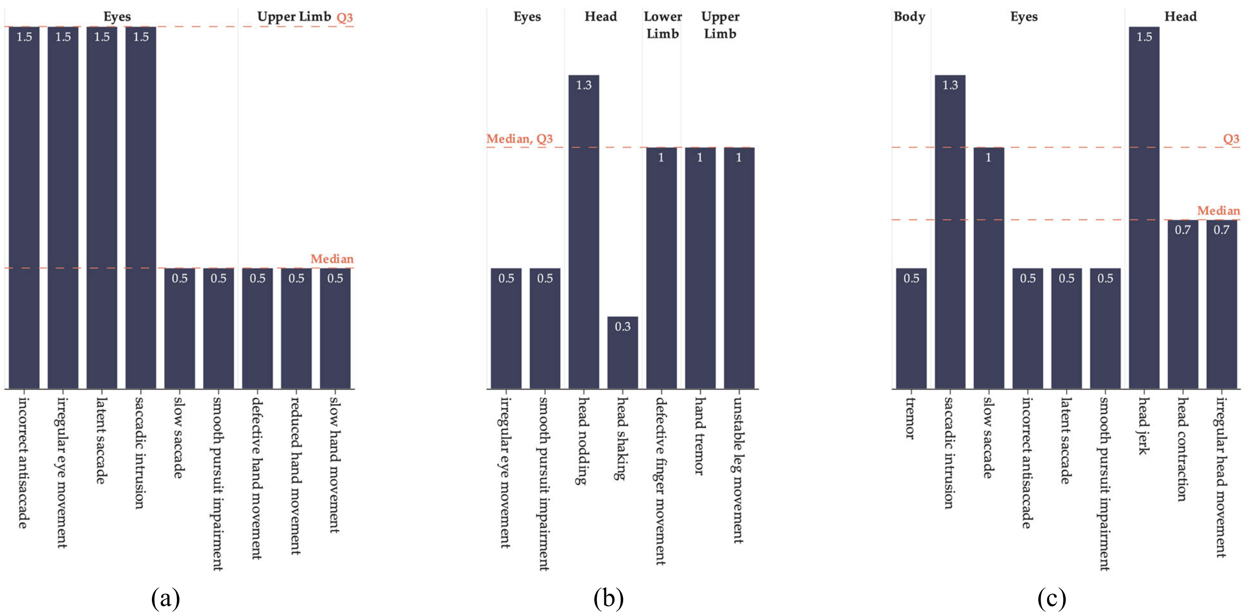

FIGURE 11. CSI values for (a) Alzheimer's disease, (b) bobble-head doll syndrome and (c) Huntington's disease and the corresponding correlated abnormal body actions.

we need to take into consideration a number of the papers that studied this relationship and the relation strength (strong, moderate, weak) established in each paper. Naturally, the more papers have studied a disease-to-body language relation, and the stronger the evidence for the relation is established, the stronger the relation becomes.

Definition 1: Let d and b denote a disease/pain and an abnormal body action, respectively. The **correlation strength index** of the disease/pain d to the abnormal body action b is defined as:

$$CSI\ (d \rightarrow b) = \frac{w_1 \cdot |s| + w_2 \cdot |m| + w_3 \cdot |w|}{w_1 + w_2 + w_3} \quad (1)$$

where w_1, w_2, w_3 are relationship weights, and $|s|, |m|, |w|$ are the number of the papers with strong, moderate, and weak evidence for the relationship, respectively.

Remark. The relationship weights can generally be defined as ‘‘dynamic’’ based on some factors, such as the number of

TABLE 21. The selected ABL elements for pains where the CSIs are greater than 0.5.

Selected Abnormal Body Actions for Pains		
body rigidity	arm pointing, hand pointing	reduced neck backward bent
irregular body movement	irregular head movement	finger pointing
facial pain expression	head forward bent	
head turn	reduced neck forward bent	

TABLE 22. The selected ABL elements for Alzheimer's disease where the CSIs are greater than 0.5.

Selected Abnormal Body Actions for Alzheimer's Disease	
incorrect antisaccade	latent saccade
irregular eye movement	saccadic intrusion

TABLE 23. The selected ABL elements for bobblehead doll syndrome where CSI is greater than 0.5.

Selected Abnormal Body Actions for Bobble-Head Doll Syndrome	
head nodding	hand tremor
defective finger movement	unstable leg movement

TABLE 24. The selected ABL elements for Huntington's disease where the CSIs are greater than 0.5.

Selected Abnormal Body Actions for Huntington's Disease		
head contraction	irregular head movement	slow saccade
head jerk	saccadic intrusion	

papers studied, the corresponding relationships, the strength levels established, the number of subjects (patients), etc. In this paper, we choose 3, 2 and 1 as the values of w_1, w_2, w_3, respectively.

We demonstrate the evaluation of the CSI for the specific pair of disease and abnormal body action in the following example.

Example. Let d = "Parkinson's disease" and b = "slow hand movement." Based on Table S1 (Figure 6), $|s| = 2$, $|m| = 4$ and $|w| = 0$. Then

$$CSI\ (d \rightarrow b) = \frac{3 \cdot 2 + 2 \cdot 4 + 1 \cdot 0}{3 + 2 + 1} = \frac{14}{6} \approx 2.3 \qquad (2)$$

The CSI values for all the disease/pain and abnormal body action pairs defined above are given in Tables S3-S7 and depicted in Figures 9-11.

We can select strongly correlated abnormal body actions for each disease or pain based on the CSI values using a "reliability" threshold. Generally, such a threshold can be statistical values such as mean, median, quartile, or any meaningful value. We formalize this idea in the following definition of "*Strongly Correlated Abnormalities Selection*."

Definition 2: Let d and $B = \{b_1, b_2, \ldots, b_k\}$ denote a disease/pain and a set of k abnormal body actions, respectively. The **strongly correlated abnormalities selection** (SCAS) of disease/pain d with respect to a threshold t is a subset $B' = \{b_{i_1}, b_{i_2}, \ldots, b_{i_n}\}$ of the set B where for each $b \in B'$, $CSI\ (d \rightarrow b) > t$, and for each $b \in B - B'$, $CSI\ (d \rightarrow b) \leq t$.

The application of SCAS to the obtained lists of abnormal body actions caused by diseases and pains allows us to select the most trustworthy sub-lists subjective to selected thresholds.

For instance, if we choose 0.5 as a threshold value, then, for each discussed condition above, we obtain the following lists of abnormal body actions where their CSI values are greater than 0.5, as presented in Tables 20-24.

These obtained abnormal body actions can now be considered as bodily signs and symptoms of the corresponding diseases. The selection of abnormal body actions for pains and diseases is subjective to the reviewed papers, the information provided in these papers and most importantly, the data selected for the analysis in the research. To obtain more complete and accurate lists of abnormal body actions, one should review a more significant number of related papers and use other information, such as the number of patients and healthy controls included in the study, the applied methodologies, etc., from these papers.

Further, we investigate "all diseases/pains-to-abnormal body action" mappings that help to identify all diseases and pains causing a specific abnormal body action, which is important in diagnosing diseases and pains from abnormal body actions as their external signs and symptoms. Using Tables 12-19, we can extract the list of diseases and pains for each abnormal body action given in these mapping tables. Since the analysis of all such mappings is again a tedious task, we focus on analyzing the top three abnormal body

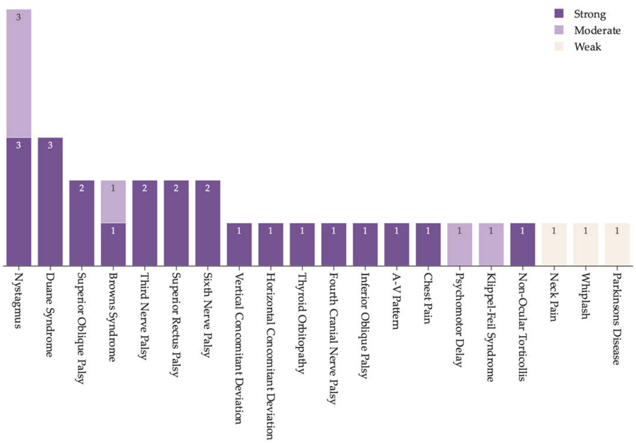

FIGURE 12. The diseases and pains causing head turn movement.

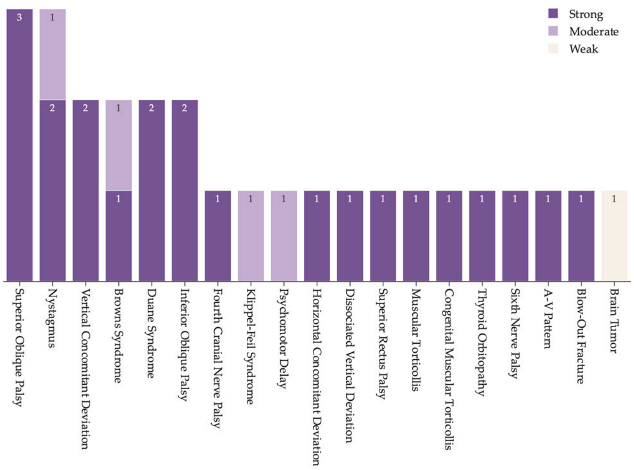

FIGURE 13. The diseases and pains causing head tilt movement.

actions, namely, "head turn," "head tilt," and "chin up." Figures 12-14 represent the mappings of diseases and pains to these abnormal body actions and the strength levels of the relations (the details can be found in Tables S8-S10).

After replacing each bar in the figures above with the bars representing the CSI values of disease/pain-to-abnormal body action mappings, we obtain Figures 15-17 (the details can be found in Tables S8-S10), which are more informative to select strongly correlated diseases and pains with the considered abnormal body actions.

In the following definition, we formalize the selection of highly correlated diseases and pains with an abnormal body action.

Definition 3: Let $D = \{d_1, d_2, \ldots, d_k\}$ and b denote a set of k diseases/pains and abnormal body action, respectively. The **strongly correlated diseases selection** (SCDS) of abnormal body action b with respect to a threshold t is a subset $D = \left\{d_{i_1}, d_{i_2}, \ldots, d_{i_n}\right\}$ of the set D where for each $d \in D'$, $CSI\ (d \rightarrow b) > t$, and for each $d \in D - D'$, $CSI\ (d \rightarrow b) \leq t$.

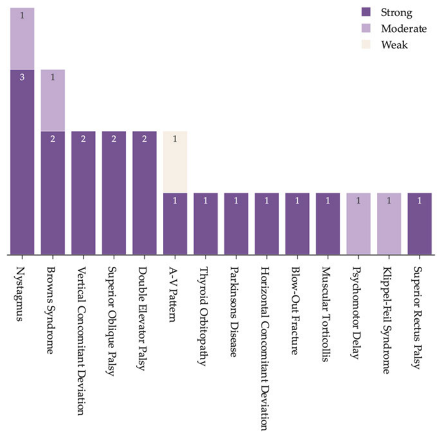

FIGURE 14. The diseases and pains causing chin-up movement.

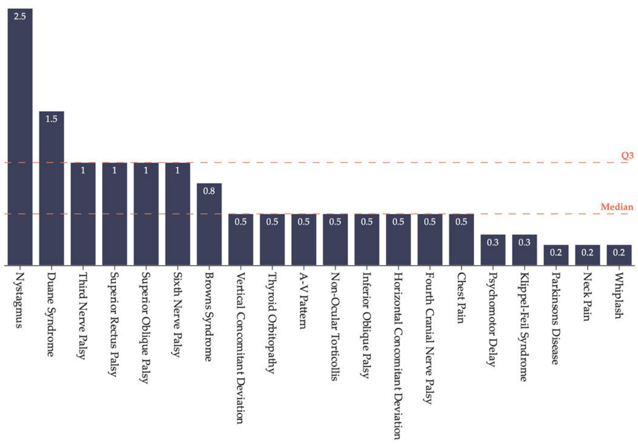

FIGURE 15. CSI values for head turn and the corresponding correlated diseases and pains.

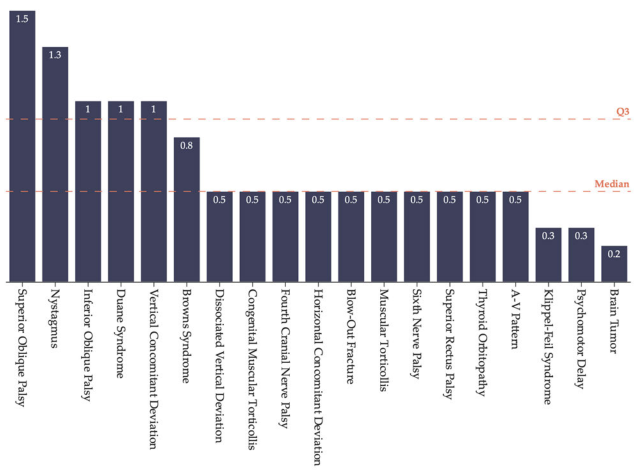

FIGURE 16. CSI values for head tilt and the corresponding correlated diseases and pains.

As a result, by choosing the threshold value of 0.5, we obtain the following list of strongly correlated diseases and pains with each abnormal body action we discuss in Tables 25-27.

TABLE 25. The selected diseases and pains for a head turn where the CSIs are greater than 0.5.

Selected Diseases and Pains for Head Turn		
nystagmus	sixth nerve palsy	Brown's syndrome
Duane syndrome	superior rectus palsy	pain
superior oblique palsy	third nerve palsy	

TABLE 26. The selected diseases and pains for head tilt where the CSIs are greater than 0.5.

Selected Diseases and Pains for Head Tilt		
superior oblique palsy	Duane syndrome	vertical concomitant deviation
nystagmus	inferior oblique palsy	Brown's syndrome

TABLE 27. The selected diseases and pains for chin-up where the CSIs are greater than 0.5.

Selected Diseases and Pains for Chin-Up		
nystagmus	superior oblique palsy	double elevator palsy
browns syndrome	vertical concomitant deviation	A-V pattern

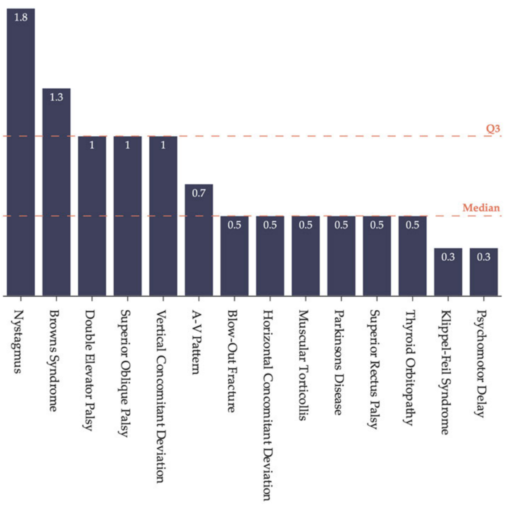

FIGURE 17. CSI values for chin-up and the corresponding correlated diseases and pains.

VI. CONCLUSION

The paper reviewed and analyzed 129 medical (healthcare) papers (out of 780 collected ones) studying the causational relationships of diseases and pains with abnormal body actions (i.e., postures, movements, expressions, and gestures). The review stage (Section III) of the research involved identifying the relationships of diseases and pains with abnormal body actions, their strengths and other necessary and interesting information provided in the reviewed papers. The mapping stage (Section IV) in the tables clearly represented the causational relationships of diseases and pains to abnormal body actions. In both stages, the review findings are organized according to the expressible body parts, i.e., body, head, neck, shoulder, face, eyes, upper limbs and lower limbs.

Based on the information provided in Sections III and IV, we built up the dataset to conduct descriptive and exploratory analyses on diseases, pains, abnormal body actions, abnormality patterns, and different relations between features represented in Section V. To define complete and trustworthy lists of abnormal body actions caused by diseases and pains, we introduced new formulas called *correlation strength index*, *strongly correlated abnormality selection* and *strongly correlated disease selection*, which allowed us to aggregate different strength rates of the evidence and based on this measurement, to select all abnormal body actions caused by a specific disease or pain as well as all diseases and pains causing a specific abnormal body action.

The definition of such complete and accurate lists of abnormal body actions caused by diseases and pains and comprehensive lists of diseases and pains causing abnormal body actions are significant in developing reliable AI-based smart systems that monitor sick people's or patients' health conditions. Firstly, machine (deep) learning systems that detect, recognize, and assess the patients' body language can clearly identify body abnormalities caused by a specific disease or pain and precisely analyze any changes in the physical and psychological conditions of the patients. Secondly, intelligent systems knowing all diseases and pains causing specific abnormal body actions can enhance the automatic diagnosis of proficiencies of health conditions using patients' bodily abnormalities as external signs and symptoms of diseases and pains.

Though we have conducted a comprehensive review and analysis, our research has few objective limitations. As we mentioned earlier, this study is broader than deeper by its approach: we have tried to consider a more comprehensive range of abnormalities that may happen in all expressible parts of the body, which affects the completeness of accuracy of the obtained abnormality sets above. For example, in Figure 5, one can see that Parkinson's disease causes abnormalities in all body parts, which is established in 39 papers. When we step down to the abnormal body actions that happened in these body parts, the correlation indications established in the papers are disturbed to the 42 abnormality elements (Figure 6), which weakens the causational relationships, reducing the number of evidence for each abnormality element, (''curse of dimensionality''). In order to strengthen each correlation, for instance, five times, we need to review another 150 papers. This problem can also be solved by researching ''deeper'' instead of ''wider'': on the one hand, the causational relationships of a specific disease (e.g., Parkinson's disease, Huntington's disease) or a family of related diseases (e.g., neurodegenerative diseases, ocular diseases) to body abnormalities should be reviewed separately; on the other hand, the abnormal body actions of each body part caused from diseases should be studied independently. In both cases, the proposed data analysis-based approach in the paper can still be used to any scale or extent.

Thus, we will concentrate on the in-depth study of the abnormality patterns happening in each expressible body part as well as the comprehensive investigation of the abnormalities caused by specific diseases or disease families as our future research prospects. We will also explore the interdependent correlations between abnormalities occurring in various body parts, not limited to the relationships between diseases and abnormalities.

Another important direction for future research is to enhance the dataset with all relevant information related to the research context within the domain. Here, we can include details about the clinical and laboratory research environment, the methodologies and techniques employed in the studies, and the number of patients and healthy controls to accurately establish correlation strengths. We can also consider the inherent characteristics of abnormalities such as movement irregularities, direction, range, velocity, latency, rhythm, posture displacement, rotation, and tilt angle, among others. This comprehensive examination is crucial to accurately characterize and understand the nature of abnormalities, resulting in precise monitoring, analysis, detection, and recognition of specific abnormalities, as well as diagnosing external symptoms of diseases using machine learning techniques.

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