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Aspects of speech rate and regularity in Parkinson's disease

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ABSTRACT

The hypokinetic dysarthria of Parkinson's disease (PD) has been defined as a multidimensional impairment leading to abnormalities in speech breathing, phonation, articulation and prosody. The aspect of prosody can be subdivided into further dimensions, as for example stress and accentuation, intonation variability and speech rate and regularity. According to available data from literature and findings of our own published studies, the present review illuminates the concept that inconstancies of speech fluency in PD are characterized by modifications of the arrangement of speech pauses and by a tendency of pace acceleration in the course of the performance. Furthermore, on the level of single utterances, Parkinsonian speakers feature significant difficulties to steadily repeat single syllables without accelerating or slowing down the pace as we were able to show in a series of published investigations. Evidence from literature and our own work justifies the hypothesis that the characteristic abnormalities in speech articulatory rate and regularity might serve as a marker of disease progression in PD.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder characterized by progressive loss of dopaminergic neurons, primarily in the substantia nigra pars compacta, and affects 1–2% of people with age over 60 years [1]. According to the Braak staging, PD begins as a synucleopathy in non-dopaminergic structures of the lower brainstem or in the olfactory bulb with subsequent rostral progression and affection of the substantia nigra [2]. The progressive dopaminergic loss is associated with a variety of motor and non-motor deficits in PD patients. In addition to the most ostensible symptoms as muscular rigidity, tremor, bradykinesia and postural instability, many patients develop a distinctive alteration of speech characterized as hypokinetic dysarthria. In a survey, the prevalence of dysarthria in PD was about 70% [3]. Affected patients may complain about a weak voice and about difficulties to get speech started. Dysarthria can emerge at any stage of the disease and worsen in the later stages [4,5], causing a progressive loss of communication and leading to social isolation. Already James Parkinson noted in his “essay on the shaking palsy” that PD patients often became “scarcely intelligible” in the course of the disease [6].

1.1. Description of the hypokinetic dysarthria

Based upon the perceptual analysis of a large sample of dysarthric speakers, Darley, Aronson and Brown primarily defined a salient cluster of deviant speech dimensions in Parkinsonian dysarthria including a harsh breathy voice quality, reduced variability of pitch and loudness, reduced stress, imprecise consonant articulation and short rushes of speech interrupted by inappropriate periods of silence [7,8]. Together, these features give hypokinetic dysarthria its distinctive gestalt of a flat, attenuated and sometimes accelerated quality which has been attributed to a reduced range of articulatory movement [7,8]. Logeman and colleagues established a general profile of hypokinetic dysarthria in a group of 200 PD patients, where almost 90% had voice disorders characterized by hoarseness, roughness, tremulousness and breathiness [9]. About half of the speakers featured articulatory problems, and 20% had speech rate abnormalities characterized by syllable repetitions, irregularities of syllable length and excessive speech pauses. According to this study, the authors supposed voice abnormalities to be the prominent attribute of hypokinetic dysarthria with the assumption of further subgroups including articulatory and speech rate deviations. These suggestions were consolidated by the findings of Zwirner and Barnes who confirmed the higher frequency of laryngeal than articulatory impairment in PD, maybe as an evidence that hypokinetic dysarthria tends to begin with laryngeal manifestation [10]. In a further investigation on a large group of PD patients performed by Ho and colleagues, voice impairment was present even in the early stages of the disease with additional articulatory deficits and disturbance of fluency in the more advanced stages of PD [4]. Though, changes of speech rate and regularity were also observed in a subgroup of only mildly affected patients leading to the hypothesis that fluency deficits might be an isolated feature of hypokinetic dysarthria independent from voice and articulatory impairment [4].

Since this first systematic characterization of hypokinetic dysarthria, there has been a wealth of subsequent investigations based upon perceptual, acoustical and electrophysiological methods which

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further refined the description of speech disturbance in PD. In summary, hypokinetic dysarthria has been defined as a multidimensional impairment leading to abnormalities in speech breathing, phonation, articulation and prosody [11] and therefore may include any or a combination of the following: hypophonia (low voice volume and vocal decay) [12], dysphonia (a breathy, hoarse or harsh voice quality) [13], hypokinetic articulation (imprecise consonants and vowels due to reduced range of articulatory movements), dysprosodia (reduced voice pitch inflections, or monotone and rushed, dysfluent, hesitant, or stuttered-like speech) [14]. These speech problems have been traditionally attributed to muscle rigidity and hypokinesia secondary to dopamine deficiency [15]. Though, data from the literature draw a contradictory picture of the influences of dopamine on hypokinetic dysarthria which does not necessarily respond to adequate medication for motor symptoms, shows a week correlation to global motor impairment and further seems to differ considerably between Parkinsonian individuals and across the levodopa cycle [11,16,17].

1.2. Speech rate and regularity in PD: literature

While plenty of widely homogeneous data on abnormalities of voice and articulation in PD have advanced the understanding of hypokinetic dysarthria on the segmental speech level, data concerning speech rate and regularity in Parkinsonian speakers are much less consistent.

Some examiners documented slow syllable repetition rates in PD speakers [18,19]; in contrast, there are further studies giving proof of accelerated alternate motion rates, sometimes with further evidence of reduced amplitude of articulator movements at least in some speakers [20–23]. It has been suggested that abnormally fast syllable repetition rates in PD speakers indicate a mode of speech with a loss of voluntary control [22]. This hypothesis seems to be substantiated by the finding that there are at least some PD speakers who have difficulty altering speech rate when requested [19]. A similar phenomenon of heterogeneous speech rates in PD has been found when related to connected speech tasks [24–27]. Weismer stated that PD patients may produce speech at a faster rate because of articulatory difficulties, in which patients may “blur contrast” between different speech sound, causing an increased speech rate [27]. Impaired self-timing for motor movements has also been offered as an explanation for the increased articulation rate sometimes seen in PD [28]. However, there were further studies on speech rate in PD which demonstrated slower speaking rates at least in a subgroup of patients [19,26,29]. As these extreme rate disturbances were found in both directions (i.e., slower and faster), the mean rate differences between PD and control speakers were not found to be significant due to a highly heterogeneous overall group performance [26,30].

Moreover, some additional aspects related to speech pauses and between-syllable durational differences complete the features of dysprosody in Parkinsonian speech. Although Canter found no differences between Parkinsonian and control subjects in number of pauses or mean pause duration during reading [29], several studies demonstrated such abnormalities. PD speakers' have been shown to exhibit a higher percentage of pauses within speech samples [26,31] with inconsistent findings concerning the number of pauses which have been found to occur slightly more or less frequently. Illes and colleagues found an increased frequency and duration of speech pauses exceeding 200 ms. These hesitations tended to be longer and occur more frequently at the beginning of sentences, which may be evidence for impaired speech initiation. There was also an increase in the number of words between silent intervals which perceptually are recognized as short “rushes” of speech in PD [32]. Moreover, the authors discovered that PD speakers exhibited fewer interjections and “modalizations” (comments that bear on verbal behavior) during narrative speech, suggesting that silent speech pauses are displayed instead of fillers [32]. Additionally, stuttering-like speech dysfluencies called “palilalia” have been observed in some individuals with PD [8,33]. Palilalia, sometimes referred to as autoecholalia, is the compulsive repetition of utterances, often in a context of increasing speech rate and decreasing loudness and is considered to probably reflect damage to inhibitory motor circuits that help terminate action [34].

The discrepant findings concerning speech rate and regularity in Parkinsonian speakers exemplified by the cited literature might have several reasons: the degree of overall dysarthria and speech rate abnormalities in particular have been found to vary between individual patients and might further be influenced by overall motor impairment, stage of the disease, cognitive function and medication [e.g. 4,9,17,26]. Therefore, the small sample sizes of the aforementioned studies including only 2 to 30 participants and a possible heterogeneity of the tested PD groups in different stages of the disease and under uncontrolled therapeutic regimen might be responsible for the inconsistent findings. Furthermore, the results of studies on speech impairment are influenced by the methodology since speech performance depends to some degree on the underlying task and might differ relevantly between conversional speech, reading or non-speech verbal performance [e.g. 35–37].

The aim of the present paper is to give a comprehensive review of our previously published studies on speech rate and regularity in speakers with PD with special emphasis on potentials of the method for the monitoring of disease progression.

2. Speech rate and regularity in PD: investigations of the author

2.1. Speech rate and regularity in connected speech [38,39]

2.1.1. Methods

At the time of the examinations, PD patients were in their best “on”-state on stable dopaminergic medication since at least 4 weeks prior to the examination. Patients were scored according to Hoehn&Yahr stages and UPDRS Motor Scale (UPDRS III). Medication with anticholinergics, cholinesterase inhibitors and atypical neuroleptics and severe dementia (Mini Mental State Examination<25 pts.) were exclusion criteria. Each participant had to perform a standardized speech task consisting of a given reading passage composed of four complex sentences which were digitally recorded for subsequent acoustic analysis performed by a special speech software (Praat© [40]). Based on the oscillographic sound pressure signal, articulation rate and articulation/pause time ratios were calculated by measuring the length of each syllable and each speech pause respectively. Additionally, articulation rate was separately calculated for the first and last sentence of the task to define a measure of articulatory acceleration.

Based upon these methods, the following investigations on speech rate and regularity are compendiously summarized:

2.1.2. Speech rate [38]

In a study on 121 Parkinsonian speakers and 70 healthy controls, there were found no differences in overall speech rate between PD and control subjects, but a significant acceleration in the course of reading in the PD speakers only when comparing net speech rates of the first and last sentence of the task. Disease duration was found to be negatively correlated with articulatory rate. Furthermore, PD patients exhibited a significantly reduced percental pause duration in relation to total speech time in the first sentence and made significantly less but longer pauses at the end of words. This characteristic speech-to-pause ratio pattern with less numerous but longer speech pauses in Parkinsonian speakers has been interpreted as an impaired regularity and timing organization of speech [39].

2.1.3. Speech rate in the course of the disease [39]

In a longitudinal study on 50 patients with PD which underwent the aforementioned readings test at baseline and again after at least 7 months (range: 7 to 79 months, mean: 25.02/SD: 17.44) articulation

rate showed a significant decline over time, although general motor impairment remained widely stable between first and second examination. As mean disease duration on first examination was about 6 years, the findings seem to locate the phase of speech rate deterioration into a more advanced stage of disease, whereas general disease progression is thought to be more rapid in the early stages of disease [41]. This assumption seems to be confirmed by a previous investigation of Ho and colleagues on a large sample of 200 patients with PD in different stages of disease, where impairment of speech fluency was found in the more severe stages, but also – in a small subgroup of patients – as an isolated symptom independent from the presence of voice and articulatory deficits [4]. Additionally, worsening of speech performance seems to follow an individual course, as there was no correlation between changes of speech parameters and the time period passed between the visits in our investigation.

2.2. Instability of syllable repetition [42–44,55]

2.2.1. Methods

At the time of the examinations, PD patients were in their best "on"-state on stable dopaminergic medication since at least 4 weeks prior to the examination. Patients were scored according to Hoehn&Yahr stages and UPDRS Motor Scale (UPDRS III). Medication with anticholinergics, cholinesterase inhibitors and atypical neuroleptics and severe dementia (Mini Mental State Examination<25 pts.) were exclusion criteria. Each participant was asked to repeat the syllable /pa/ at least 25 times in a "comfortable" self chosen steady (isochronous) pace without accelerating or slowing articulatory velocity. Based upon the oscillographic sound pressure signal of the recorded audio material, the period from onset of one vocalization until the following vocalization was defined as "interval". Only the first 20 utterances were taken for the definite analyses in order to avoid a modification of participants' articulatory velocity by the expectance of the imminent end of the task. Stability of pace of the utterances was defined as relative coefficient of variation calculated for the intervals 5 to 20 in relation to the average interval length of the first 4 syllables which was defined as "reference interval duration". This procedure was based upon the hypothesis that the first utterances are necessary for the definition of the individual articulatory pace which has to be maintained throughout the ongoing speech task. This approach seemed to be justified since there were no indications for relevant speech initiation problems in the tested groups of Parkinsonian speakers which would have systematically influenced the value of the reference interval duration. Furthermore, average interval length of the intervals 5 to 12 and of the intervals 13 to 20 were related to the reference interval and defined as "relative pace stability" The difference between the average length of the first and second part of the task was defined as a comprehensive measure of pace acceleration, with values greater than 0 indicating an acceleration of pace.

Based upon these methods, the following investigations on speech rate and regularity are compendiously summarized:

2.2.2. Steadiness of syllable repetition [42]

The steadiness of vocal pace performance was investigated in a sample of 73 patients with PD and 43 healthy controls under the preposition that, in principle, the temporal stability of velocity and regularity of connected speech can be subdivided down to the level of single utterances. As the main result, patients with PD showed a significant unsteadiness in the execution of syllable repetition and showed a clear tendency to pace acceleration in the course of the performance. No correlations were seen between syllable repetition performance and disease duration, Hoehn&Yahr stages or UPDRS III.

2.2.3. Steadiness of syllable repetition in the course of the disease [43]

In a longitudinal investigation, 58 Parkinsonian patients were tested and re-tested after at least 12 months (mean: 33.40/range: 12 to 88) based upon the same syllable repetition paradigm. General motor impairment was similar at first and second visit. As a main result, the unsteadiness of syllable repetition and acceleration in the course of the performance both showed a further increase in the course of the disease.

2.2.4. Influence of levodopa and deep brain stimulation on syllable repetition [44]

Standardized short-term levodopa administration had no effect on the precision of syllable repetition in a group of 22 pharmacologically treated patients with PD whereas deep brain stimulation of the nucleus subthalamicus led to a further deterioration of syllable repetition steadiness observed in 14 patients tested in the stimulator ON and OFF condition.

2.2.5. Steadiness of syllable repetition under complex conditions [45]

In a further development of the initial syllable repetition task 64 patients with PD and 40 healthy control speakers had to repeat a single syllable (/pa/) or a pair of alternating syllables (/pa-ti/) in a self chosen steady (isochronous) pace (test 2) or in a given pace of 80/min (test 3a and 3b) or 60/min (test 4a and 4b). The maximum syllable repetition performance where participants were asked to repeat a given syllable as fast as possible (test 1) served as a measure of general articulatory capacity (Table 1). Again, percental coefficient of variance of interval length was measured for the description of pace stability throughout the performance. As a result, patients with PD showed significant aberrations of the steadiness of pace throughout the performance of the different syllable repetition tasks although the maximum syllable repetition capacity was similar in the PD and control group. In Parkinsonian speakers, the coefficient of variance was elevated in the tasks consisting of a single syllable repetition and showed a further increase in the alternating syllable tasks where the given pace had to be kept. These aberrations were not to be explained by general articulatory impairment in the Parkinsonian speakers since maximum syllable repetition capacity was unimpaired. In summary, in the PD group, pace performance was observed to be irregular in all tasks, but showed a further decline when two demands (keeping the steady pace and alternating the syllables) were present indicating an additional impairment when the complexity of the task was increased as a possible hint for an overstraining of the motor speech functions or additional executive dysfunction [45, data were presented on the MDPD congress 2011/Barcelona, Figs. 1 and 2].

Table 1
Listing of the different tests [43].

Test 1: syllable repetition as fast as possible (number of syllables in 5 s)			
Test 1.1.: /pa/	Test 1.2.: /ta/	→Mean value of test 1.1. and test 1.2.	→Test 1a
Test 1.3.: /pa-ko/	Test 1.4.: /pa-ti/	→Mean value of test 1.3. and test 1.4.	→Test 1b
Test 2: self chosen isochronous pace (COV)			
Test 2.l.: /pa/	Test 2.2.:/ta/	→Mean value of test 2.1. and test 2.2.	→Test 2
Test 3: paced syllable repetition /80/min (COV)			
Test 3.l.: /pa/	Test 3.2.: /ta/	→Mean value of test 3.1. and test 3.2.	→Test 3a
Test 3.3.: /pa-ko/	Test 3.4.: /pa-ti/	→Mean value of test 3.3. and test 3.4.	→Test 3b
Test 4: paced syllable repetition /60/min (COV)			
Test 4.l.: /pa/	Test 4.2.:/ta/	→Mean value of test 4.1. and test 4.2.	→Test 4a
Test 4.3.: /pa-ko/	Test 4.4.:/pa-ti/	→Mean value of test 4.3. and test 4.4.	→Test 4b

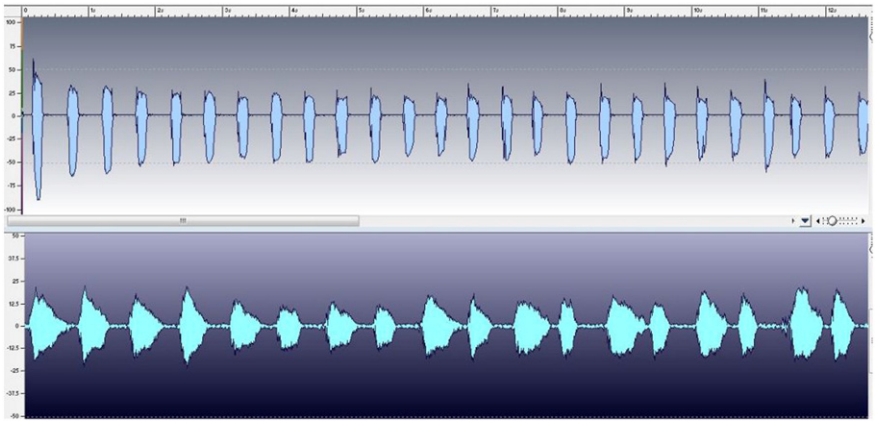

Fig. 1. Comparison of COV of test 2 (repetition of the syllable /pa/ in a self-chosen steady pace) in a healthy subject (above) and a speaker with PD (below).

3. Discussion

According to the presented data of our group, patients with PD feature difficulties concerning the steady performance of speech and non-speech utterances which are characterized by specific changes of speech pauses and articulatory acceleration in the course of reading and a similar pattern of articulatory instability and acceleration in the course of syllable repetition. Recent functional magnetic resonance imaging (fMRI) studies in healthy speakers were able to unravel the components of the basic network of brain areas engaged in the motor control of speech and the underlying processes of syllable repetition and sequencing [e.g. 46]. Besides widespread cortical areas, there are also subcortical areas involved in the processes of syllable repetition and sequencing as parts of the cerebellum, thalamus, and basal ganglia. Vocalization of simple articulatory gestures has been shown to be associated with concurrent activation and connectivity of the mesencephalic periaqueductal gray matter, neocortical areas and elements of basal ganglia thalamocortical circuitry [47]. Furthermore, according to the Directions Into Velocities of Articulators (DIVA) model, speech and phoneme representations which are thought to be stored in parts of the left inferior frontal cortex, are indifferent to the semantic meaning of the sounds; thus, they are activated and transformed into a speech motor program whenever the speaker is producing elementary nonsemantic utterances comparable to the demands in the current study [48]. The production of monosyllabic utterances consisting of consonant and vowel (as performed in the cited syllable repetition studies of our group) has been shown to go along with activation of the cortical areas in combination with basal ganglia and additionally the cerebellum which facilitates rapid and coordinated movements required for consonant production [e.g. 49,50]. On the other hand, the basal ganglia have been hypothesized to be crucial for the initiation and maintenance of a speech motor program, to switch from one articulatory gesture to the other and to suppress competitive articulatory gestures. Although – according to these briefly explicated models derived from investigations on healthy speakers – the basal ganglia obviously play an essential role in speech motor processing, functional imaging data on Parkinsonian speakers are sparse. Recent fMRI analyses of the motor network in Parkinsonian patients revealed a reduced functional connectivity which was at least partially normalized by dopaminergic stimulation [e.g. 51,52]. Related to the domain of motor speech performance, a loss of connectivity between the involved neuronal networks might be responsible for the observed impairments in PD especially under raising complexity of tasks implicating the temporal domain since time processing in general has been shown to be dopamine dependent [e.g. 53]. Related to the presented results of our group, there was a striking similarity between the patterns of altered rate and regularity observed in connected speech and syllable repetition; however, our data do not allow the conclusion that speech and non-speech verbal gestures – although resorting to the same muscles and movements – share identical motor control circuits. According to the available data on healthy subjects, the basic motor speech network dynamically shows an increased engagement and recruitment of additional brain areas dependent from the complexity of the

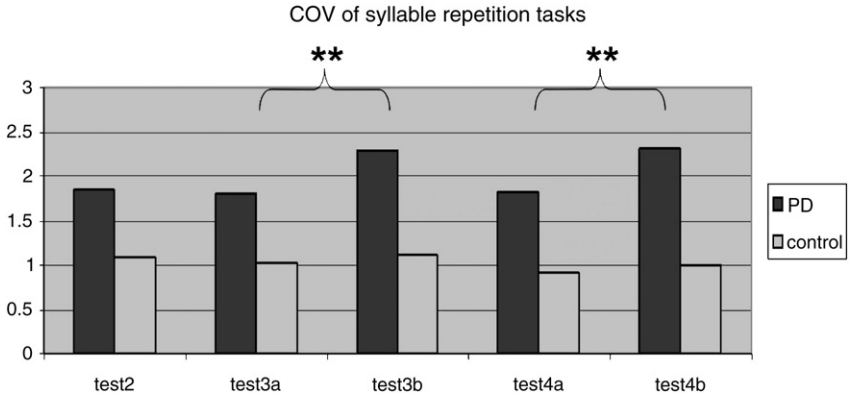

Fig. 2. Comparison of coefficient of variance (COV) in PD and control speakers: COV in the subtests with alternating syllables (test 3b and test 4b) was even worse than in the accordant subtest with single syllable repetition (test 3a and 4a) in the PD group (paired t-test, ** = $p<0.01$).

utterances [54–56]. Therefore, one might presume that speech production based upon a reading task involves higher-level cortical function as e.g. attention and additional visual capacities which probably superimpose and modulate the patterns of more automated speech production required for syllable repetition.

In general, the characteristic basal ganglia dysfunction in PD is thought to be responsible for an instability of motor sequences which normally are performed in an automatic fashion and which require little attentional resources [57]. The resulting instability of motor sequences involves aspects of abnormal scaling and amplitude of movement, abnormal sensory processing and deficits in internal cueing. These abnormalities can be observed in PD related to the execution of repetitive movements within different modalities [58–60] and can partially be improved by voluntary attention or the use of external cues [61,62] as a kind of compensation for the impairment of automaticity [63]. Specifically, correlations have been found between speech abnormalities and some aspects of gait disturbance in PD [64–66]. Moreau and coworkers reported a correlation between oral festination and festination of gait which both were interpreted as axial symptoms of PD [64]. Cantiniaux and colleagues examined 11 patients with PD under deep brain stimulation (DBS) and found similar features of impaired velocity and pause ratios of gait and speech which were not influenced by DBS or levodopa [65]. Furthermore, a close correlation between speech pause ratios and some distinctive symptoms as gait disturbance and postural instability were reported in a large sample of 169 patients with PD [66]. Since axial symptoms as gait and postural imbalance typically define the later stages of the disease and have shown to be widely refractory to dopaminergic or surgical treatment the question arises to what extent the same is true for distinctive aspects of speech disturbance, particularly speech rate and regularity. Following this approach, one might hypothesize that measurement of speech rate and regularity could turn out to be a useful tool for the monitoring of disease progression as it is suggested by the exemplified longitudinal studies of our group where abnormalities of speech rate showed a significant deterioration in the follow-up investigations of a group moderately impaired patients. In the same vein, Ho and coworkers found disturbance of fluency in the more advanced stages of PD, however, with a subgroup of patients who featured isolated speech rate abnormalities at the very beginning of the disease which again points to the problem of group heterogeneity in PD [4].

One putative limitation of the presented findings of our group could be the fact that the speech investigations were performed on Parkinsonian speakers who were under dopaminergic medication and therefore, a possible pharmacological influence could not definitely be excluded. However, previous investigations of our group showed no effect of levodopa administration on speech rate and syllable repetition capacity [16,42]. Furthermore, the two cited longitudinal studies on dysprosody and syllable repetition performance in a large sample of medicated PD patients revealed a decline of speech velocity and syllable repetition capacity independent from global motor impairment which was widely stable over time. But, since dopaminergic medication had been augmented in many patients between the two examinations, negative pharmacological effects cannot reliably be excluded.

4. Summary

According to the exemplified studies of our group, abnormalities of speech rate while reading and syllable repetition in Parkinsonian speakers feature some phenomenological similarities and show a characteristic further deterioration in the course of the disease. Although a possible influence of dopaminergic medication on these functions cannot definitely be excluded by the described studies, there are some conclusive arguments for non-dopaminergic mechanisms of the maintenance of speech rate and regularity which warrant a further development and refinement of speech tasks as an instrument for the monitoring of disease progression in PD. Furthermore, the preliminary findings of a correlation between speech rate abnormalities and gait disturbance [62,63] require further investigation to reveal a possible shared pathophysiology.

Conflict of interest

None.

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