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Research Article

Evaluation of Efferent Auditory System and Hearing Quality in Parkinson's Disease: Is the Difficulty in Speech Understanding in Complex Listening Conditions Related to Neural Degeneration or Aging?

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Purpose: The effects of neurological diseases on the auditory system have been a notable issue for investigators because the auditory pathway is closely associated with neural systems. The purposes of this study are to evaluate the efferent auditory system function and hearing quality in Parkinson's disease (PD) and to compare the findings with age-matched individuals without PD to present a perspective on aging.
Method: The study included 35 individuals with PD (mean age of 48.50 ± 8.00 years) and 35 normal-hearing peers (mean age of 49 ± 10 years). The following tests were administered for all participants: the first section of the Speech, Spatial and Qualities of Hearing Scale; pure-tone audiometry, speech audiometry, tympanometry, and acoustic reflexes; and distortion product otoacoustic emissions (DPOAEs) and contralateral suppression of DPOAEs. SPSS Version 25 was used for statistical analyses, and values of $p < .05$ were considered statistically significant.
Results: There were no statistically significant differences in the pure-tone audiometry thresholds and DPOAE responses between the individuals with PD and their normal-hearing peers ($p = .732$). However, statistically significant differences were found between the groups in suppression levels of DPOAEs and hearing quality ($p < .05$). In addition, a statistically significant and positive correlation was found between the amount of suppression at some frequencies and the Speech, Spatial and Qualities of Hearing Scale scores.
Conclusions: This study indicates that medial olivocochlear efferent system function and the hearing quality of individuals with PD were affected adversely due to the results of PD pathophysiology on the hearing system. For optimal intervention and follow-up, tasks related to hearing quality in daily life can also be added to therapies for PD.

Parkinson's disease (PD) is a common neurodegenerative disorder caused by the degeneration of dopaminergic neurons of the substantia nigra (Pahwa & Lyons, 2013; Zhang, 2006). PD causes the emergence of cardinal motor findings, such as reduced speed and amplitude in repetitive movements, muscle rigidity, bradykinesia, and postural balance disorder (Dewey et al., 2012; Goubault et al., 2018). In addition to motor disorders, cognitive, behavioral, and autonomic symptoms are also seen in PD. These nonmotor symptoms are often overlooked but are shown to be important symptoms that adversely affect a person's quality of life (Juri et al., 2010).

Isolated hearing loss is very rare, and impaired temporal functions (especially difficulties in perception of speech in noise) with hearing loss are common conditions in the elderly (Shalash et al., 2017). It is estimated that the weakening of the neuronal network is the cause of this relationship between the increased prevalence and age (Guehl et al., 2008).

Difficulties in understanding speech in noisy environments are common in the elderly, even without hearing loss. The brainstem pathologies seen in PD cause disruptions in the auditory system (Shalash et al., 2017). While there are

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auditory processing disorders in PD (Guehl et al., 2008), there are no clear findings for understanding speech in noise, which is a subskill of auditory processing. The basic structure that provides the understanding of speech in noise is the auditory efferent system, and examination of this is needed in PD.

The main starting point for the investigation of the relationship between auditory neural structures and PD should be the pathophysiology of PD and the associated auditory structures. There are two main types of transmission paths in the auditory pathway: afferent and efferent. Sensory information is transmitted to the brain via afferent paths and from the brainstem to the cochlea via efferent paths. High-intensity sounds suppress basilar membrane activity and outer hair cell function in the inner ear, resulting in reduced amplitudes of otoacoustic emission (OAE) responses. At the molecular level, this system acts against the excitotoxicity mechanism of glutamate at the synaptic terminals through dopamine release, reducing neurocochlear activity. Therefore, distortion product otoacoustic emission (DPOAE) responses in normal-hearing people are disrupted by the presentation of contralateral white noise in studies (Guinan, 1996; Warr, 1992).

It has been poorly determined whether hearing losses are specific to PD or secondary to more complex impaired processes of sensory inputs that occur during the course of the disease (Jafari et al., 2020). At this point, the main question is whether the difficulties in perception of speech in daily life arise from aging or from neural degeneration in PD. What is meant by "speech perception" here is the discrimination of speech in noise and crowded environments in daily life, pertaining more generally to the quality of life. In order to evaluate this, hearing quality scales and OAE tests performed by presenting noise from the contralateral ear can be applied. In a study evaluating peripheral and central auditory functions in a population of individuals with PD, it was reported that they had more difficulty in hearing words spoken by other people (Folmer et al., 2017). However, in contrast to previous studies, the current study is planned to be carried out by investigating situations encountered in daily life in a slightly more functional way and by examining efferent hearing system function, which is related to speech discrimination (SD) in noise. Functional assessment of hearing quality in daily life, clinical evaluation of the efferent hearing system by suppression of OAE, and the investigation of the relationship between hearing quality and efferent auditory system function are among the points that distinguish this study from other studies.

The pathophysiology of PD is related to the degeneration of dopaminergic neurons and to dopamine depletion (Lamas et al., 2017; Lopes et al., 2019; Toro et al., 2015). According to some studies, these dopamine-related defects may cause subclinical cochlear damage, and DPOAE responses in individuals with PD were found to be lower than those of individuals without PD at almost all frequencies tested. Thus, even if the DPOAE responses, which are cochlear responses after dopamine treatment, do not reach normal levels, improvement can be seen compared to the patients' previous conditions (Garrett et al., 2011; Pisani et al., 2015; Wang et al., 2014). On the contrary, De Keyser et al. observed increased DPOAE in a group of individuals with PD who did not receive dopaminergic treatment compared to individuals without PD (De Keyser et al., 2019). In this study, there is no research hypothesis related to dopamine treatment; it will be investigated whether there is a difference in efferent auditory system functions and hearing quality of life between individuals with PD who received dopamine treatment at stable dosages and have similar clinical histories and age-matched individuals without PD.

Natural aging processes and specific neurodegenerations in PD may adversely affect cochlear transduction mechanisms (Vitale et al., 2012). Therefore, investigating the function of cochlear mechanisms and assessment of hearing-related quality of life in individuals with PD is vital in following treatments. In addition, based on the age of onset and the Parkinson's phenotype, it has been noted that older age of onset is characterized by a more severe motor and nonmotor phenotype (Pagano et al., 2016). In this context, in the selection of participants, although the onset ages of PD of the individuals in the study group vary, the time since diagnosis is between 1 year and 3 years. Nevertheless, in order to rule out the differences that may be caused by early onset, it was also aimed to compare the suppression values and hearing quality scores of younger individuals with PD compared to older ones. To control the age-related effects, the values of the study group were compared with age-matched individuals without PD. In light of these strategies, one of the aims of this study is to evaluate efferent auditory system function and hearing quality and to reveal the relationship between them in individuals with PD. Another aim is to investigate whether efferent hearing system dysfunction and/or poor quality of hearing in daily life is caused by neurodegeneration due to PD or aging in individuals with PD. Unlike previous studies on PD, this study applies a comprehensive test battery to evaluate the efferent auditory system and quality of hearing and it has included a larger number of participants. The OAE and suppression tests to evaluate the cochlea and the efferent hearing system; the Speech, Spatial and Qualities of Hearing Scale (SSQ) to evaluate the quality of hearing; and routine audiometric tests to evaluate peripheral hearing and speech comprehension skills are applied. As a result of this study, it is aimed to improve hearing performance in daily life and thus the overall quality of life by making positive contributions to the follow-up and treatment processes of individuals with PD.

Method

Participants

This study was conducted in the Audiology Department of the Faculty of Health Sciences of Gazi University and was approved by the Gazi University Ethics Committee. All enrolled individuals agreed to participate in the

study and signed an informed consent form prior to the investigation.

Individuals with PD (n = 35) aged 29–63 years and normal-hearing peers (n = 35) were included in this study. The group of age-matched individuals without PD was used to control age effects. To exclude differences that could be caused by early onset, the suppression values and hearing quality scores of younger individuals with PD were compared with those of the older ones. It was thought that investigating the effects of PD pathophysiology on hearing quality and the efferent hearing system from the very beginning of diagnosis would be important in terms of providing an advantage for early intervention. In addition, individuals with early-onset and late-onset PD were included in this study to provide insight into hearing quality and efferent auditory system function in all PD age groups.

The study group included patients with a diagnosis of PD of between 1 year and 3 years who were showing typical cognitive features. Community-dwelling individuals were diagnosed with idiopathic PD by a neurologist according to the UK Brain Bank criteria (Hughes et al., 2001). The Montréal Cognitive Assessment test was used to assess cognitive skills and was administered by subject-accredited researchers in the physical therapy rehabilitation department. The individuals with scores of 26 or above were considered normal (Carson et al., 2018), and those with lower scores were excluded from the study. Individuals who had middle ear pathologies, had multiple disorders or other neurological diseases besides PD, had experienced noise-induced hearing loss, underwent dosage regulation during dopaminergic therapy, had undergone an ear operation, or could not concentrate for the tests were excluded. Among the individuals without PD, those who had normal-hearing thresholds, were neurologically healthy, and had no history of ear operation, noise-induced hearing loss, or middle ear problems were included.

In the PD group, the time of diagnosis, drugs taken daily, and motor stage of the disease according to Hoehn and Yahr were recorded (Zhao et al., 2010). All individuals from the PD group were evaluated when the disease had a decrease in characteristic features and they were in Stage I or II. Individuals in Stages I and II were selected for the study group in order to prevent the stages of PD from affecting hearing functions as a confounding variable. In addition, one of the most important points in sample selection was the selection of age-matched individuals without PD.

Evaluation Tools

First, a case report form and the SSQ Turkish version (Gatehouse & Noble, 2004; Kılıç, 2017) were completed by all individuals. The SSQ consists of three main topics: hearing of speech, spatial perception, and hearing quality. Questions under the heading of "Hearing of Speech" include situations with competitive voices, the audibility of other speakers, the number of people involved in a conversation, and the characteristics of the location (silence, echo, noise, other different sounds, etc.). The questions in the "Spatial Perception" section aim to distinguish the motion component as well as direction and distance. It is mostly for individuals who use hearing aids. Under the heading of "Hearing Quality," there are items that evaluate the distinction, definition, clarity, and naturalness of the sounds heard and the effort made while listening. In this study, only questions about "Hearing of Speech," which is the first part of the SSQ, were applied for all individuals. The content of the questions includes understanding in noise in general, distinguishing sounds in a crowd, listening skills, following speech, and so forth. The degree of difficulty in such skills is evaluated. A score of 10 points indicates "I am very good at this skill" while 0 points means "I am absolutely bad." Individuals score the items themselves between 0 and 10 according to their own experiences.

Considering the clinical procedures, participants underwent pure-tone and speech audiometry testing in a silent cabin with air-conduction thresholds at frequencies of 125–8000 Hz and bone-conduction thresholds at 500–4000 Hz to evaluate peripheral hearing. Individuals with limits of perception lower than 20 dB HL at all frequencies were defined as normal (Clark, 1981). Speech audiometry was evaluated in terms of speech recognition threshold (SRT) and SD scores. In the SRT test, a three-syllable word list was read with a live voice, asking the participants to repeat the words they heard by turning on the microphone of the audiometer with supra-aural headphones in the silent cabin. If there were at least three correct repetitions for every five words, the level of intensity at which the speech was presented was reduced. This was continued until the threshold level was found. In the SD test, by adding approximately 40 dB to the SRT thresholds of the participants, lists consisting of 25 words of one syllable were read with a live voice at the level of intensity at which the participant heard comfortably and the participant was asked to repeat them. The number of correctly repeated words was calculated as a percentage. For tympanometric and ipsilateral–contralateral acoustic reflex measurements, a 226-Hz probe tone was used. These measurements provided information about the condition of the middle ear and eardrums, as well as the function of the auditory reflex arc.

In addition to these tests, DPOAEs were measured at 65 dB SPL for f1 and 55 dB SPL for f2 frequencies. The frequency ratio of the two primary tones (f2/f1) was fixed at 1.22. DPOAEs at 2f1-f2 were considered available if the signal-to-noise ratio (SNR) was at least 3 dB between 1 and 6 kHz. The DPOAE test was used to find out how well the participants' cochleae worked. There are outer hair cells in the inner ear that respond to sound by vibrating as a function of cochlear mechanism. The values given in the results section are the SNRs of the inner ear response to sound in DPOAE measurements.

To evaluate medial olivocochlear (MOC) reflexes, the white noise at 50 dB SPL presented on the contralateral ear side during DPOAE measurement and the SNRs on each side were recorded. For suppression of DPOAEs, if the criterion of an amplitude decrease of > 1 dB was taken into account, a suppressive effect was obvious in individuals

(Berlin et al., 1994; Giraud et al., 1995). The values given as suppression in the results section are the amount of decrease that occurred due to the presentation of contralateral noise in the SNR of routine responses in DPOAE measurements. In normal individuals, in order to protect the ear against any acoustic trauma from a negative stimulus such as noise, inner ear mechanisms are expected to raise a defense and the DPOAE responses of hair cells are thus expected to decrease. However, the MOC reflex may not be fully functional in the presence of noise in individuals with neurological disorders or defects in the efferent hearing system that provides this defense. Therefore, this test was used in this study to investigate MOC reflex function in individuals with PD, a neurological disease. Since the MOC reflex measurements are related to the response of the inner ear in the presence of noise, it was planned to investigate the relationship with the questions in the "Hearing of Speech" section of the SSQ as a qualitative measurement. Clinically, the OAE suppression test is a test that can evaluate the response of the efferent hearing system and the cochlea when noise stimulus is presented. Functionally, the equivalent of this in daily life can be evaluated with scales such as the SSQ, which indicates speech understanding in noisy environments. That is why it is very important to investigate the relationship between SSQ and the amount of suppression in OAE.

Statistical Analyses

SPSS Version 25 was used for statistical analyses, and values of $p < .05$ were considered statistically significant. The variables were investigated using visual (histogram and probability plots) and analytical (Kolmogorov–Smirnov/Shapiro–Wilk test) methods to determine whether or not they were normally distributed. Descriptive analyses were presented using mean and standard deviation for normally distributed variables. The p values were obtained by the independent-samples t test in both groups for pure-tone hearing threshold averages, SRT and SD scores, DPOAE SNR and DPOAE suppression levels, and SSQ scores. In order to exclude differences that might be caused by early onset, the mean age of the PD group was calculated and the suppression amounts and SSQ scores of individuals below and above the mean age were compared using the Mann–Whitney U test. Additionally, since the data were distributed normally, the relationships between SSQ scores and DPOAE suppression amounts were examined with the Pearson correlation test.

Results

According to the inclusion and exclusion criteria, 35 individuals with PD and 35 individuals without PD were included. The mean age of individuals with PD was 48.50 ± 8.00 years (range: 29–63 years; 15 of them were women) and that of individuals without PD was 49 ± 10 years (29–64 years; 20 of them women). Individuals who had been diagnosed with PD for a minimum of 1 year were evaluated in this study, and the duration of PD diagnosis was found to be 16 ± 4 months. Accordingly, considering the mean age of the PD group and the duration of PD, these individuals have a PD onset age of between 47.50 and 51 years. These findings were given in this study as the only descriptive statistics. The average Montréal Cognitive Assessment score of individuals with PD was found to be 27.05 ± .60.

Suppression amounts and SSQ scores were compared between those within the PD group above and below the mean age of 48.50 years to exclude differences that might be caused by the early onset of PD. As a result, no statistically significant difference was found between those diagnosed with PD at earlier ages and those diagnosed with PD at later ages in terms of SSQ scores and suppression amounts ($p = .790$, $U = 137.000$, $p = .685$, $U = 145.000$).

Considering the clinical procedure, when the audiological findings were investigated, the hearing thresholds were analyzed based on the averaged value of the right and left ears at four frequencies (500 Hz, 1, 2, and 4 kHz) and described as the average pure-tone audiometric (PTA) threshold. The PTA values of individuals with PD were compared with those of individuals without PD, and no statistically significant difference was determined ($t = 0.489$, $p = .732$). The PTA values of both groups were in the normal-hearing range according to American Speech-Language-Hearing Association protocol (Clark, 1981). There were no statistically significant differences between the speech audiometry test scores ($t = .771$, $p = .075$) and hearing thresholds of both groups (see Tables 1 and 2). All individuals had a Type A curve; thus, the middle ear pressures and the static compliances were in the normal range.

The acoustic reflex thresholds of individuals with PD were higher than those of individuals without PD as

Table 1. SRT and *SD* scores of groups.

SRT and *SD* scores								
	Group 1				**Group 2**			
	M	***SD***	**Maximum**	**Minimum**	***M***	***SD***	**Maximum**	**Minimum**
SRT	8.14	4.71	15.00	.00	7.29	4.59	15.00	.00
SD	88.57	5.41	100.00	80.00	88.80	5.72	100.00	80.00

Note. Group 1: individuals without PD; Group 2: individuals with PD. SRT = speech recognition threshold; PD = Parkinson's disease.

Table 2. Pure-tone audiometric thresholds of groups.

Pure-tone frequencies	Ear side	Group 1 (dB)	Group 2 (dB)	*p*	*t*
500 Hz, *M* ± *SD*	Right	6.57 ± 4.33	5.85 ± 3.73	.089	2.135
	Left	7.11 ± 3.52	9.07 ± 4.12	.913	.380
1 kHz, *M* ± *SD*	Right	10.35 ± 4.11	10.38 ± 3.57	.232	1.562
	Left	9.75 ± 4.13	10.23 ± 2.75	.881	2.034
2 kHz, *M* ± *SD*	Right	12.93 ± 2.30	11.90 ± 3.60	.078	1.114
	Left	12.67 ± 3.40	11.25 ± 3.65	.125	.640
4 kHz, *M* ± *SD*	Right	10.95 ± 5.43	12.09 ± 0.88	.772	1.624
	Left	12.52 ± 3.60	10.06 ± 2.20	.536	.882
6 kHz, *M* ± *SD*	Right	12.26 ± 2.25	13.06 ± 2.05	.565	.182
	Left	13.10 ± 2.60	14.25 ± 2.45	.099	1.507
8 kHz, *M* ± *SD*	Right	14.10 ± .50	15.06 ± 2.03	.108	.853
	Left	15.05 ± 2.50	15.15 ± .60	.095	2.650

Note. Group 1: individuals without PD; Group 2: individuals with PD. PD = Parkinson's disease.

ipsilateral and contralateral measurements, but, interestingly, there was no statistically significant difference in any frequencies of the groups ($t = 2.675$, $p = .145$).

There were no significant differences at any frequencies of the groups for DPOAE responses. The DPOAE responses of the left ear were similar to those of the right ear in both groups. Similarly, SNRs at 4 and 6 kHz were lower than those of other frequencies and there were no significant differences between groups at any frequencies. The DPOAE responses were also not statistically different between the right and left ears in both groups (see details in Table 3). As expected, contralateral noise stimulation caused suppression of the OAE responses in individuals with PD and without PD, but what should be particularly noted here is how suppressing it is and whether there is a difference between the two groups in this respect.

The suppression level of response at 1 kHz in the right ear was 0.73 ± 0.60 dB in individuals with PD and 2.57 ± 0.98 dB in individuals without PD, and there was a statistically significant difference between the groups ($p = .019$), as was also the case for the left ear ($p = .024$). At 2 kHz for both ears, there were statistically significant differences ($p = .000$, $p = .015$). On the contrary, there were no statistically significant differences between the groups in responses at 4 and 6 kHz in the left ears (respectively, $p = .403$ and $p = .080$). Additionally, the highest suppression levels were observed at 1 and 2 kHz in the individuals without PD (see Table 4).

There was a statistically significant difference between the groups in SSQ scores; accordingly, the hearing quality of individuals with PD was lower than that of the individuals without PD (see Table 5; $p = .042$, $t = 2.003$).

When the correlation between the SSQ scores and suppression amounts reflecting the efferent hearing system function were examined, *p* values and correlation coefficients for 1, 2, 4, and 6 kHz for the right ear were as follows, respectively: $p = .048$ and $r = +.632$, $p = .045$ and $r = +.311$, $p = .859$ and $r = +.220$, and $p = .017$ and $r = +.284$. The same values for the left ear were as follows, respectively: $p = .027$ and $r = +.265$, $p = .556$ and $r = .077$, $p = .583$ and $r = +.067$, and $p = .208$ and $r = +.152$.

Discussion

Experimental studies have confirmed the presence of different dopaminergic receptors in afferent and efferent neural auditory pathways (Guehl et al., 2008; Jafari et al., 2020). As PD is mostly seen in the elderly, it should be determined whether deterioration in hearing quality is caused by aging or by PD-related degeneration. There is

Table 3. Distortion product otoacoustic emission (DPOAE) amplitude (SNR by dB) of individuals with PD and without PD (right and left ears).

DPOAE	Ear side	Group 1 (dB)	Group 2 (dB)	*p*	*t*
1 kHz, *M* ± *SD*	Right	12.28 ± 2.81	12.78 ± 4.18	.059	.579
	Left	12.21 ± 2.52	11.08 ± 3.04	.575	.251
2 kHz, *M* ± *SD*	Right	9.76 ± 3.01	8.88 ± 2.43	.185	1.329
	Left	9.83 ± 2.97	9.17 ± 2.51	.301	.997
4 kHz, *M* ± *SD*	Right	9.54 ± 2.20	6.80 ± 2.60	.774	1.614
	Left	9.6 ± 2.20	8.10 ± 2.50	.753	2.644
6 kHz, *M* ± *SD*	Right	7.95 ± 1.43	6.09 ± .97	.811	.763
	Left	8.06 ± 1.53	5.6 ± 1.93	.894	.672

Note. Group 1: individuals without PD; Group 2: individuals with PD. PD = Parkinson's disease; SNR = signal-to-noise ratio.

Table 4. Distortion product otoacoustic emission (DPOAE) suppression level of individuals with PD and without PD.

DPOAE	Ear side	Group 1 (dB)	Group 2 (dB)	*p*	*t*
1 kHz, *M* ± *SD*	Right	2.57 ± .98	.73 ± .60	.019*	2.938
	Left	2.39 ± 1.25	.91 ± 1.95	.024*	5.551
2 kHz, *M* ± *SD*	Right	2.03 ± .22	.75 ± 1.41	.000*	.617
	Left	2.28 ± .91	.83 ± 1.86	.015*	3.025
4 kHz, *M* ± *SD*	Right	1.61 ± 1.20	–1.07 ± .31	.000*	8.178
	Left	1.50 ± .97	1.43 ± .36	.403	.673
6 kHz, *M* ± *SD*	Right	1.59 ± 1.14	.60 ± .80	.037*	2.321
	Left	1.86 ± 1.03	.90 ± .94	.080	2.125

Note. Group 1: individuals without PD; Group 2: individuals with PD. PD = Parkinson's disease.
*$p < .05$ (independent-samples *t* test).

a need for comprehensive research on hearing quality and efferent auditory system function in individuals with PD.

This study started with the aim of revealing whether hearing impairment is affected by efferent auditory system function and hearing quality in daily life in individuals with PD. As mentioned in the introduction, DPOAE can demonstrate the functioning of the MOC efferents, which are suppressed by the responses of outer hair cells in the presence of contralateral white noise (Ashmore, 2008; Guinan, 2018). Considering the effect of the auditory brainstem and other structures in the pathophysiological relationships of PD, the findings of the study are consistent with our hypothesis. As a result of the poor performance of the olivocochlear system due to the effect of PD on the efferent auditory tract, basilar membrane activity and outer hair cell functions are not sufficiently suppressed in the presence of contralateral noise and the expected decrease in the amplitudes of OAE responses was not observed as in the control group. Considering that we excluded issues such as hearing loss, ototoxicity, medication, and cognitive problems by our inclusion–exclusion criteria and also included a control group, it can be easily explained that this decrease in OAE response amplitudes is related to the pathophysiology of PD and the auditory structures that it affects. In this context, the results of our study also reflect the approaches of other studies in that affected cochlear structures in PD may cause limitations in the expected normal suppression levels (Lopes et al., 2019; Pisani et al., 2015). In relation to dopamine in PD pathophysiology, the effects of dopaminergic receptors on the functioning of DPOAE and outer hair cells, which are effective in the amplitude of the cochlear microphonic, have been proven in experimental animal studies (Kim et al., 2013; Maison et al., 2012; Valdés-Baizabal et al., 2015). When some variables such as age, clinical picture, and cognitive skills are excluded, the poor efferent auditory system function in the PD group compared to the control group may be due to molecular changes in PD pathophysiology in our study, as well. In related diseases such as Parkinson's, problems with the dopamine decarboxylation mechanism and deficiencies in the storage and recovery of this neurotransmitter in synaptic vesicles appear to be associated with disruptions in the nonlinear cochlear mechanism (Ryu et al., 2018). Similarly, Lopes et al. concluded that the effect of olivocochlear efferent systems was reduced (Lopes et al., 2019), and in our study, suppression levels in the PD group were seen to be adversely affected by dysfunction of the efferent auditory system. Similarly, in another study, DPOAE responses were found to be lower in the PD group than in individuals without PD at almost all frequencies tested due to dopamine defects in PD pathophysiology, suggesting subclinical cochlear damage (Pisani et al., 2015). Based on this, in this study, one more step was added to the battery; by adding the suppression test to the OAE and SSQ testing, it was revealed whether the defects caused by PD are a reflection of this in the efferent hearing system and in daily life. However, in this study, there was no comparison of results before/after dopamine treatment, and individuals who received similar treatments (physical therapy and rehabilitation) for PD were selected to avoid confounding variables. Therefore, attributing poor efferent system function and poor hearing quality in individuals with PD to molecular changes such as dopamine in PD pathophysiology may not be reliable. In this study, no drug efficacy or pre/post-application evaluations were implemented; only hearing quality and efferent hearing systems of individuals with PD selected homogeneously in terms of diagnosis and treatment were compared with those of normal-hearing peers, and significant differences were found. Contrary to this study, there are results that showed no differences in auditory functionality between individuals with PD and without PD during treatment (De Keyser et al., 2019). This difference may be due to factors such as differences in the

Table 5. Speech, Spatial and Qualities of Hearing Scale (SSQ) scores of individuals with PD and without PD.

Groups/SSQ scores	*N*	*M*	*SD*	*p*	*t*
Group 1	35	8.60	1.73	.042*	2.003
Group 2	35	7.80	1.49		

Note. Group 1: individuals without PD; Group 2: individuals with PD. PD = Parkinson's disease.
*$p < .05$ (independent-samples *t* test).

auditory skills evaluated, the characteristics of the individuals included, and the number of participating individuals. Tests evaluating primary auditory functions such as tonal audiometry, speech audiometry, and OAE were used in De Keyser et al.'s study. However, in our current study, suppression tests and a high-frequency audiometer were also applied to go one step beyond the routine test battery. In addition, the sample size (n = 50) of that earlier study is smaller than the sample size in our current study (n = 70). Sample size may affect many factors, from the statistical method to statistical significance. Finally, in our current study, homogeneity was sought in terms of age, age at diagnosis, medical history, and so forth. All of these factors can be counted among the reasons for the different results from the other studies.

Furthermore, it has been reported in many studies that auditory comprehension in noise in old age is impaired (Nair & Basheer, 2017; Shojaei et al., 2016). Regarding PD, there are studies suggesting that there may be changes in the phenotype and effects of the disease depending on the age of onset (Pagano et al., 2016). In this study, in order to prevent the effects of early onset age on hearing performance in PD, suppression amounts and SSQ scores of individuals below and above the mean age were compared within the PD group and no significant difference was found. In addition, in order to rule out age-related effects, age-matched individuals without PD were compared with individuals with PD; it was revealed that the dysfunction in the efferent system in individuals with PD was caused by neural degeneration due to PD, and thus the quality of hearing in daily life was impaired. Efferent hearing system functions, which are related to the performance of SD in noise, are closely related to auditory discrimination in difficult listening conditions encountered in daily life, speech understanding in crowded environments, and SD in noise. As a result, positive correlations were found between the amounts of suppression in the OAE test performed by presenting noise from the contralateral ear and the SSQ scores evaluating the quality of hearing in daily life.

Interestingly, although the DPOAE amplitudes of individuals with PD were lower than those of individuals without PD, the results revealed no statistically significant difference in this regard. This finding might be a result of normal cochlear structures and outer hair cells, even if the efferent system is affected in PD. Additionally, the amplitude of DPOAE response and suppression levels at higher frequencies (4 and 6 kHz) were lower than those at other frequencies, which can be explained by the potentially insufficient intensity of the stimulus to conduct research at higher frequencies. As there were no significant differences between the two groups in terms of age, routine SD scores, hearing thresholds, and DPOAE responses, the finding of low hearing quality in individuals with PD obtained via SSQ scores may be due to the dysfunctional efferent hearing system in these individuals. However, there are weak correlations between SSQ scores and suppression amounts at most frequencies. Therefore, stronger evidence is needed to report that it is the dysfunctions in the efferent hearing system that cause poor hearing quality as assessed by the SSQ.

There is little research about the efferent auditory pathway and hearing quality in individuals with PD, and our findings have shed new light on these issues. Careful eligibility criteria were utilized in this study to rule out possible confounding factors, such as other otologic and neurologic problems, noise exposure, onset age of PD, and aging effects in the auditory system. Among the most important strengths of this work are including an age-matched control group to exclude age effects and comparing early- and late-onset data within the PD group to exclude early-onset PD effects. Audiological tests were selected according to the study objectives, and this methodological care contributed to demonstrating the effects of PD on the auditory system. Conducting comprehensive audiological evaluations, performing OAE measurements as well as suppression tests, using the SSQ to measure the reflections of noise comprehension skills in daily life, and examining the correlation of SSQ scores with clinical findings are among the distinctive points of this study compared to other works. In this context, the data obtained in this study contribute to the expansion of auditory profiles and the development of specific approaches to clinical diagnostic follow-up and better communication rehabilitation strategies for this population. Unlike previous studies in the literature (Lopes et al., 2019), in this study, we applied a questionnaire (the SSQ) for speech understanding in noise as well as performing OAE suppression measurements. This study contributes to filling the gaps in the existing knowledge about PD and the auditory system. This is important for developing rehabilitation strategies that promote better communication skills and, accordingly, better quality of life.

Among the limitations of this study, the potentially insufficient sample size of the PD group can be given; nevertheless, this study differs from previous studies in that it used different tests, including SSQ and suppression testing. In future studies, it is recommended to investigate the efferent hearing system using a more extensive test battery (including auditory brainstem response tests) for different neurological disorders.

In conclusion, this study recommends the inclusion of exercises such as speech understanding in noise, perception of target stimuli in competing stimuli, auditory attention, and auditory memory in noise, which are skills related to the efferent hearing system and evaluated by the SSQ, in therapy sessions and in comprehensive follow-up of individuals with PD. Furthermore, weakness in the efferent system and low quality of hearing in daily life were detected in individuals with PD regardless of age in our study. Thus, it is necessary to do exercises with individuals with PD on the mentioned skills in order to prevent such weakness and to follow an optimal therapy program. In order to evaluate the results of these efforts objectively, it is recommended to apply scales such as the SSQ intermittently. However, there is a need for future comprehensive research involving cognitive tests and clinical noise discrimination tests.

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