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Developing a wearable device for upper extremity tremors

Sercan Dogukan YILDIZ[1], Gazi AKGUN[2], Dilek GUNAL[3], Erkan KAPLANOGLU[4], M. Caner AKUNER[2], Umit S. SEHIRLI[5]

[1] Department of Anatomy, Faculty of Dentistry, Istanbul Kent University, Beyoğlu, Istanbul, Turkey
[2] Control and Automation Systems Division, Department of Mecatronics Engineering, Faculty of Technology, Marmara University, Maltepe, Istanbul, Turkey
[3] Department of Neurology, School of Medicine, Marmara University, Pendik, Istanbul, Turkey
[4] Department of Computer Science and Engineering, University of Tennessee, Chattanooga, USA
[5] Department of Anatomy, School of Medicine, Marmara University, Maltepe, Istanbul, Turkey

Corresponding Author: Sercan Doğukan YILDIZ
E-mail: sercandogukanyildiz@gmail.com

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ABSTRACT

Objective: This project aims to develop a wearable device to suppress both the essential and resting tremor and investigate its effectiveness.

Materials and Methods: This study details the development and assessment of a wearable device for upper extremity tremors. The wearable device underwent a comprehensive design and a prototype was produced with a 3D-printer. To refine the functionality of the prototype, a motor that mimics tremor was attached to a 3D-printed prototype. Then, the printed prototype was applied to the hand model, and tested its effectiveness for tremor suppressing. The wearable device was further investigated on patients with essential tremor and Parkinson`s disease seeking treatment at Neurology Clinics. We recorded the tremor data and processed and visualized the recorded data by using the MatLab (version R2021a, MathWorks Inc., USA) software.

Results: The wearable device effectively decreased the tremors both during the simulation phase and the patient testing phase. The data from the wearable device revealed a notable decrease in the amplitude of the tremor. This decrease signifies an achievement of tremor suppression.

Conclusion: The prototype of the wearable device signifies a remarkable efficacy in tremor supression. It holds promise for being a potential solution to alleviate the tremor symptoms of essential tremor and Parkinson`s disease patients.

Keywords: Wearable device, Essential Tremor, Parkinson`s Disease

1. INTRODUCTION

Tremors, most commonly seen among adults, are characterized by involuntary rhythmic and oscillatory movements of the body parts [1,2]. It commonly contracts agonist and antogonist muscles repeatedly. Tremors are predominantly central types, encompassing cortico-lenticular-thalamic-cortical and cortico-cerebellar pathways.

Essential tremor (ET) is a chronic and progressive disorder and its primary clinical feature is kinetic tremor with the frequency ranging between 4-10 Hertz (Hz) [3,4]. According to the International Parkinson and Movement Disorder Society, ET is defined as a bilateral upper extremity action tremor, which is potentially accompanied by such as head tremor, voice tremor, or lower extremity tremors without co-occuring dystonia, ataxia, or Parkinson's disease (PD) symptoms and persists for at least 3 years [5, 6].

The term of ET was first used by Pietro Burresi in 1874 [7]. In a global context, ET is a movement disorder associated with physical and psychological disabilities with a prevalence of 0.4% to 3.9% in the general population [8]. Notably, in the United States of America (USA), seven million patients are estimated to suffer from ET, representing approximately 2.2% of the population [9].

Although, ET is generally considered to be bening, it negatively impacts the overall quality of patients' lives [10, 11]. Patients with tremors generally feel social embarrasment and avoid drinking, eating or writing in public [12, 13].

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Parkinson's disease is the second most prevalent neurodegenerative disorder after Alzheimer's disease. Its prevalence increases with age, affecting around 1% of individuals aged 65 and above and approximately 4% of individuals over 80 years old [14]. PD is a chronic neurodegenerative disorder characterized by the degeneration of dopaminergic neurons in the substantia nigra pars compacta. This progressive disease results in motor and cognitive impairments, with bradykinesia, resting tremor, rigidity, and postural instability being its key clinical features. The tremor observed in PD is termed as resting tremor and typically presents itself asymmetrically. Pronation and supination movements are affected more common than flexion and extension movements [2].

Approximately 80% of ET disease cases are attributed to the familial ET (FET) gene, which is identified on chromosome 3q13 [15]. Another gene associated with ET is the ET maps (ETM) gene, and it is located on chromosome 2p22-p25 [16]. Chromosome 6p23 was reported to be associated with ET [17]. Mutations in fused in sarcoma (FUS), an RNA-binding protein, have been detected in ET patients, and similar pathogenic mutations have also been observed in patients with fronto-temporal dementia (FTD) and amyotrophic lateral sclerosis (ALS) [18]. The leucine-rich repeat and Ig domain containing 1 (LINGO1) gene has also been implicated in the pathophysiology of ET [19]. The condition of neurotransmitter deficiency has not been identified in ET patients. Despite these genetic insights, the precise mechanism behind tremor manifestation and the source and mechanism of pathological oscillations remain elusive.

In the treatment of ET, medications developed for other disorders are heavily relied on as there is no curative treatment for ET [20]. However, the existing medications have proven effective in symptomatic management of ET [18]. In cases where medical intervention fails or side effects become intolerable, surgical intervention such as neuromodulations, deep brain stimulation (DBS) and radiofrequency thalamotomy, gamma-knife radiothalamotomy, magnetic resonance-guided focused ultrasound (MRgFUS) may be considered [21]. It is worth noting that unilateral MRgFUS thalamotomy can result in side effects such as paresthesia and balance disturbances while bilateral thalamotomy may lead to cognitive impairments, postural disturbances, balance issues, and speech impairments [22].

Wearable devices designed to address tremors can be broadly categorized into two main groups: active and passive. Passive devices offer resistance to tremors without incorporating moving parts. Active devices, on the other hand, can detect tremors in real-time and respond based on the body's feedback. Active devices use actuators to counteract tremors and employ mechanisms like pneumatic systems, electric motors, and hydraulic systems to dampen tremors effectively [23]. This project aims to develop an active and passive force-controlled wearable device to suppress tremor in both ET and PD and to investigate the effectiveness of the wearable device.

2. MATERIALS and METHODS

A force-controlled wearable device to address upper extremity tremors was designed at Marmara University School of Medicine and Mecatronics Engineering. The design phase was executed using SolidWorks software (version 2020 SP2.0, Dassault Systèmes Inc., USA). The physical realization of the device was executed through 3D printing technology. Specifically, we employed Ender 5 Plus 3D printer and chose PLA filament as the construction material.

The device's key feature is its full mobility, eliminating the need to attach it to a table or chair, and its capacity to be affixed on the upper extremity. The device is powered by a unit with rechargeable batteries located on the upper extremity, and its design does not impede patients' daily activities. It does not restrict the flexion, extension, ulnar and radial deviation (abduction and adduction) of the hand. Patients can also comfortably perform fine motor movements such as flexion, extension, abduction, and adduction of their fingers and hand. It allows for a full range of hand movements, enabling tasks such as writing, buttoning, holding a cup, and using utensils like forks, spoons, and knives with ease.

To mimic tremor phenomena in a controlled laboratory environment, a 3D-printed hand model was crafted. In the anatomical alignment, we affixed two motors, each of which was equipped with an unbalanced load, to the hand model. One motor was placed on lateral side of the first metacarpophalangeal joint. The other motor was affixed between the third and fourth metacarpophalangeal joints. These motors were engineered to generate tremors in three orthogonal axes, encompassing flexion-extention (X – axis), abduction-adduction (Y-axis) and supination-pronation (Z-axis). The orchestration of motor functions were facilitated through an ardinuo interface, which was controlled by MatLab (version R2021a, MathWorks Inc., USA) software. This precision allowed us to produce artificial tremors. We employed a strategically positioned accelerometer, which was located on proximal of palmar surface of the hand (Figure 1), upon activation of motors, the accelerometer recorded the movement patterns for one minute. This experimental setup enabled us to accurately capture and analyze tremor data.

For testing our prototype of the wearable device on computer, a hand was designed by SolidWorks software (version 2020 SP2.0, Dassault Systèmes Inc., USA) and then simulated hand which had a real hand`s features was transferred to the MatLab (version R2021a, MathWorks Inc., USA) software.

Our prototype of the wearable device was securely affixed to the simulated hand and a 5 Hz tremor was generated. In the subsequent step, the prototype was turned on, and data were recorded both before and after its activation. The wearable device was assembled by integrating electronic and mechanical components, and it was affixed to the hand model to perform artificial tremors. Data were obtained from the tremor model when the wearable device was both activated and de-activated.

In this study, the wearable device was applied to patients diagnosed with ET and PD. The patients were selected from individuals seeking treatment at Marmara University School

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of Medicine Department of Neurology. Four ET patients (three females and one male) and four PD patients (two females and two males) were included. All of these four patients had been suffering from their diseases for at least 5 years. None of them had undergone DBS before. The mean age of the patients was 64.4 ± 4.98 years.

All patients were right-handed, and we collected the data through the right-hand trials. All the patients were informed about the clinical study. We kindly asked the patients to flex their arms (keeping them paralel to the ground), extend their forearms, and pronate their hands for minimum 30 seconds. Movements of the hands were recorded by an accelerometer affixed to the wearable device, both when activated and deactiviated. Data were logged at a rate of four times per second and subsequently processed and visualized using MatLab (version R2021a, MathWorks Inc., USA) software.

Statistical Analysis

For statistical analysis SAS (SAS Institute Inc., USA) software was used. Analyses were presented using means.

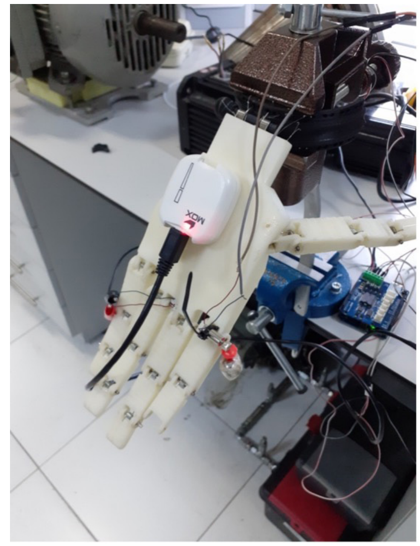

***Figure 1**. Tremor in laboratory and measurement by an accelerometer.*

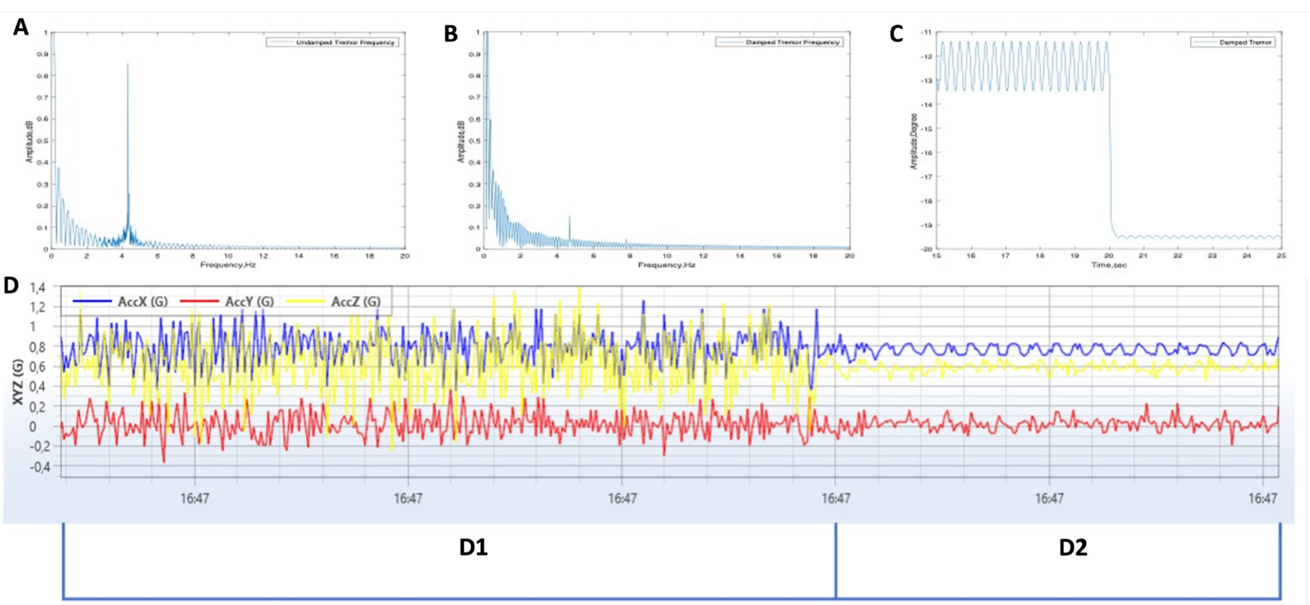

***Figure 2 A:** Frequency of tremor which is generated on computer. B: Damped tremor (the wearable device is on). C: Amplitude of damped tremor. D: Generated tremor by using motors that contain unbalanced load, D1: the wearable device is off, D2: the wearable device is on.*

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3. RESULTS

Accelerometric data analysis showed that the frequency of computer-generated tremors were approximately 5 Hz. When the wearable device was turned on in the simulation, a discernible suppression effect was observed. The amplitude of tremor decreased while the frequency of tremor remained unchanged (Figures 2A, 2B, 2C).

We affixed the wearable device on 3D-printed hand model. Subsequently, the motors equipped with unbalanced loads were activated to induce tremors. The frequency and amplitude of tremors were recorded by an accelerometer, which was attached to the wearable device (Figure 2D).

The wearable device was administered to a total of eight patients, comprising four ET patients and four PD patients.

ET patients

In the case of ET patient 1, ET patient 2, ET patient 3, the wearable device was activated on two separate occasions, in the case of ET patient 4 the wearable device was activated on three separate occasions. During each active phase, it effectively suppressed the tremor (Figure 3). During the experimental investigation of effiency, the patients maintained the specified hand position as described above.

Supression rate calculations of ET patients

Following two device activations, suppression rates were computed for each phase within the range of 4-6 Hz. Suppression rates were calculated for each axis, with mean suppressions ranging between 4-6 Hz (Table I).

PD patients

The experiment was conducted with four PD patients. The force-controlled wearable device was activated twice for all patients. Throughout the efficiency investigation experiment, all four patients maintained their hand position as described in the methods section.

For the PD patient 1, PD patient 2, PD patient 3 and PD patient 4 the wearable device effectively suppressed tremors in both active phases (Figure 4).

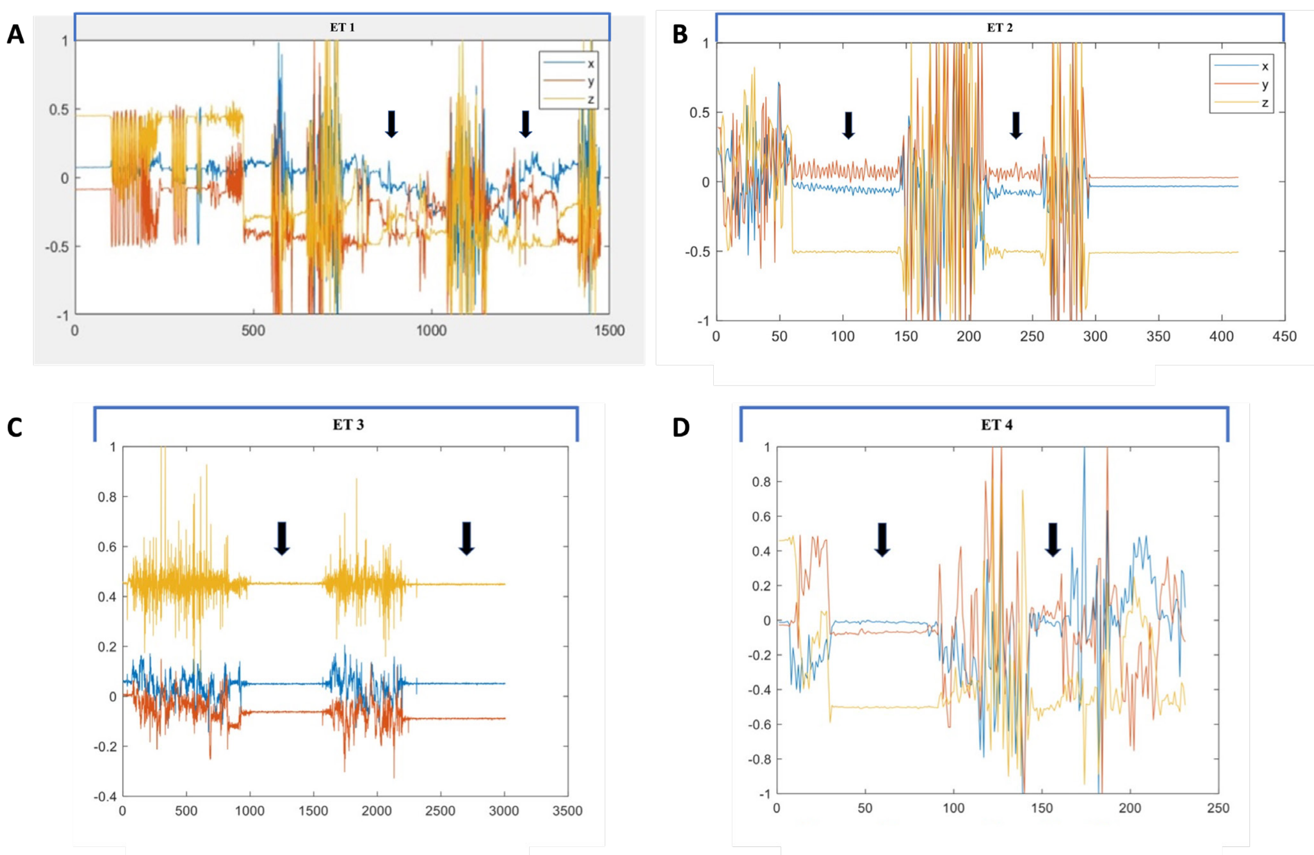

Figure 3 A: *Graphic for first ET patient, ET1: ET patient 1. B: Graphic for second ET patient, ET2: ET patient 2. C: Graphic for third ET patient, ET3: ET patient 3. D: Graphic for fourth ET patient, ET4: ET patient 4. Arrows: phases of wearable device were turned on.*

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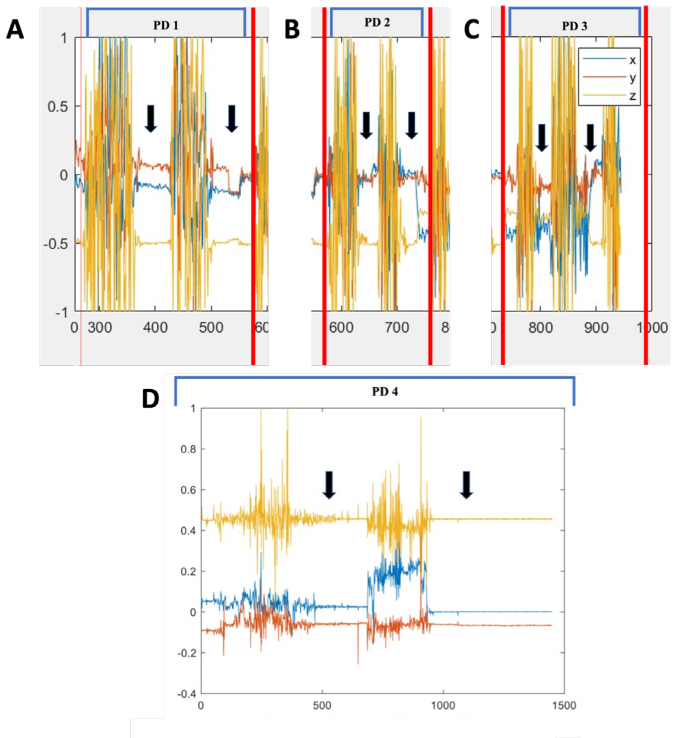

Figure 4 A: *Graphic for PD patient 1, PD 1: PD patient 1. B: Graphic for PD patient 2, PD 2: PD patient 2. C: Graphic for PD patient 3, PD 3: PD patient 3. D: Graphic for PD patient 4, PD 4: PD patient 4. Arrows: phases of wearable device were turned on.*

Table I. *Data of ET patients. Means of suppression rates of X, Y and Z axes and means of suppression rates of the phases*

	Mean suppression rate (%) X axis	Mean suppression rate (%) Y axis	Mean suppression rate (%) Z axis	Mean suppression rate (%) of X, Y and Z	Mean suppression rate (%) of phases
ET Patient 1 Phase 1	99.0818	84.2615	81.5181	88.2871	89.9182
ET Patient 1 Phase 2	89.2636	90.5513	94.8326	91.5492	
ET Patient 2 Phase 1	88.6713	86.1441	97.8149	90.8768	88.2673
ET Patient 2 Phase 2	77.7305	93.2357	86.0073	85.6578	
ET Patient 3 Phase 1	88.7549	87.6694	97.1523	91.1922	89.6474
ET Patient 3 Phase 2	81.5548	90.9011	91.8516	88.1025	
ET Patient 4 Phase 1	79.7907	56.2578	97.1351	77.7279	73.8278
ET Patient 4 Phase 2	96.713	93.6223	93.8368	94.724	
ET Patient 4 Phase 3	57.2295	69.3926	20.4729	49.0316	

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Suppression rate calculations of PD patients

Suppression rates were individually calculated for each axis, focusing on the 4-6 Hz range for all four patients (Table II).

Table II. *Data of PD patients. Means of suppression rates of X, Y and Z axes and means of suppression rates of the phases.*

	Mean suppression rate (%) X axis	Mean suppression rate (%) Y axis	Mean suppression rate (%) Z axis	Mean suppression rate (%) of X, Y and Z	Mean suppression rate (%) of phases
PD patient 1 Phase 1	80.9480	68.1980	63.3810	70.8420	77.2840
PD patient 1 Phase 2	63.8290	94.6480	92.6990	83.7250	
PD patient 2 Phase 1	90.4640	65.4750	75.5420	77.1600	76.5240
PD patient 2 Phase 2	65.0940	89.3210	73.0480	75.8880	
PD patient 3 Phase 1	67.9560	77.7160	88.6520	78.1080	79.4360
PD patient 3 Phase 2	70.6670	87.7790	83.8460	80.7640	
PD patient 4 Phase 1	84.3940	52.7754	78.2841	71.8178	83.4433
PD patient 4 Phase 2	96.895	92.4836	95.8277	95.0688	

4. DISCUSSION

Essential tremor reportedly affects 0.9% of the world population, amounting to at least seventy-two million individuals [24]. However, this number may actually be higher because there may be un-reported individuals who have limited access to medical treatment or may not deem treatment as neccessary. PD, on the other hand, has an impact over six million [25]. According to the United Nations in 2022, the global population reached eight billions, and the aging population is on the rise, with an estimated one billion people aged over sixty-five by 2030 [26]. Age is one of the main factors in the development of tremors [27]. A retrospective study spanning forty-five years found that the incidence of ET increased with age, with rates of 58.6 per 100.000 for those aged 50-59, 76.6 per 100.000 for those aged 70-70, and 84.3 per 100.000 for those aged over 80 [28].

The wearable device demonstrated successful results in both computer simulation and laboratory tests. Clinical study results further confirmed its efficiency. This study included both ET and PD patients due to the observed link between ET and PD conditions. A previous study conducted with 247 ET patients reported that 11 of 247 participants had mild PD symptoms [29]. Another study conducted with 678 ET patients reported that approximately 6.1% were also diagnosed with the PD disease [30]. Additionally, 24 participants of 130 ET patients had PD clinical criteria [31]. It was reported that childhood ET may evolve to severe PD in adult life [32].

The studies reporting the prevalence of ET widely focused on the impact of gender. Numerous studies demonstrated no significant difference based on gender, yet gender based differences were observed in some studies [24]. A study conducted in the province of Edirne, Turkey, showed higher prevalence of ET among women [33]. On the contrary, another study conducted in Şile district of Istanbul, Turkey, reported a higher prevalence of ET among men [34]. However, no statistically significant difference was reported in both of these studies.

The patients in our study were randomly selected, and all were over 50 years old right-handed female and male individuals. While, ET is typically asymmetric, we were unable to employ electomyographic measurement to determine dominant side of tremor [35]. However, patients in our study stated that the tremor afflicts their lives when the tremor is experienced on the hand used more frequently in their daily activities. It underscores the importance of addressing tremor in the hand dominantly used by patients, not just any hand.

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The wearable device was constructed using PLA filament due to its compatibility with 3D printers and several advantageous properties, such as high load-bearing capacity, impact resistance, low odor during printing, high printing speed, and recyclability. The device's weight is crucial both for daily use and tremor suppression. Research involving 50 patients has demonstrated that the addition of weights ranging from 480 g to 600 g reduced action tremor in a significant percentage (58%) of participants. It also contributed to improved performance in daily household and workplace in the 36% of those participants [36]. Applying weights ranging from 600 g to 2160 g to the wrist also reduced the magnitude of tremor in individuals with ET [37]. The wearable device in this study weighed 491 g, located on the dorsum of the hand and contribute to hand stabilization.

While many wearable device prototypes exist in the literature, majority of these active wearable prototypes have not advanced to clinical trials due to the concerns related to ergonomics, weight, size, and aesthetics for patient use [38]. The studies with these wearable devices conducted laboratory tests based on the data obtained from previous laboratory studies rather than implementing clinical trials. These laboratory trials demonstrated over 90% tremor supression rate [39, 40].

The studies involving a prototype testing with clinical trials demonstrated tremor suppression. One study involving with a PD patient achieved an 85% tremor suppression using weight and spring systems for energy transfer in passive devices [41]. In 2020, a study conducted with one PD patient reported a prototype reduced tremor by 74% to 82% [42]. Another study using a pneumatic actuator in a single ET patient reduced tremor magnitude by 70% [43]. In a pilot study using non-invasive handheld active tremor-reducing device, an average tremor supression of 73% was reported [44]. Another pilot study involving 10 PD patients showed no significant benefit from a gyroscope-spoon system for resting tremor [45].

In our study, the wearable device achieved an average tremor supression rate of 86.3792% for ET patients and 77.748% for PD patients. This result indicates a high level of patient satisfaction. Notably, the prototype has been developed, the mentioned active and passive power-controlled wearable device falls into both the active and passive device categories. Its inclusion in the passive device group is due to the fact that the device's own weight creates a damping effect on the tremor. The reason for its inclusion in the active device group is that it generates counteracting forces based on the magnitude and frequency of the tremor.

Conclusion

In summary, our comprehensive study encompassed simulation, laboratory testing, and clinical research. The wearable device not only demonstrated efficacy in simulation and laboratory settings but also achieved a high success rate in tremor supression among patients during clinical trials. A patent application has already been filed for the first prototype, with plans to extend patent protection to subsequent prototypes. The efficacy of this wearable device is promising for diminishing the impacts of upper extremity tremors of ET and PD patients.

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Compliance with the Ethical Standards

Ethical approval: The study protocol was approved by the Institutional Review Board and the Ethics Committee of Marmara University School of Medicine (Protocol number: 09.2020.420).

Conflict of interest: The authors have no conflicts of interest to declare.

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Authors' contributions: SDY, USS: Designed the study, SDY and GA: Performed the laboratory work and analysed the data, SDY and DG: Obtained data from patients and analysed the data, SDY, GA, MCA and EK: Designed the active and passive force controlled wearable device. SDY, GA: performed the statistical analysis. SDY, GA and USS: wrote the manuscript. All authors approved the final manuscript.

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