İSTANBUL UNIVERSITY-CERRAHPAŞA
INSTITUTE OF GRADUATE STUDIES

**Ph.D. THESIS**

# ANALYSIS OF TOOTHBRUSHING TECHNIQUE THROUGH PLAQUE REMOVAL SUCCESS

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**February, 2024**

# THESIS ACCEPTANCE AND APPROVAL

This thesis titled **Analysis of Toothbrushing Technique Through Plaque Removal Succsess**, prepared by Elhadi Abdalla Ammar SHKORFU under the supervision of **Assoc. Prof. Dr.** Aysel ERSOY, was accepted as a **Ph.D. Thesis** after being **consensus** approved by our jury as a result of the exam held on **16/02/2024**.

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## DECLARATION

I hereby declare that this thesis is my own work, I have not had engaged in any unethical behavior at any of the stages from planning to the writing of the thesis, I have obtained all the information in this thesis within the limits of the academic and scientific ethical rules, I have cited all the information and comments being obtained in this thesis study, and I have included these references in the list of references. During the analysis and writing stages of this thesis, I accept that I have abided by the patent and copyright rights and therefore I myself take all kinds of legal responsibility.

El Hadi Abdalla Ammar SHKORFU

(Signature)

*I give my gratefulness to Allah for blessing me with the physical and mental strength that has enabled me to see this endeavor through to fruition. I am interested in dedicating this thesis to the most important people in my life. In addition, I would want to express my gratitude to both my superior and the committee that monitors for providing me with feedback and suggestions. There are not nearly enough words in the English language to communicate the depth of my appreciation to everyone who helped me finish my thesis...*

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February, 2024 El Hadi Abdalla Ammar SHKORFU

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| Symbols | Description |
|---|---|
| **ADA** | : American Dental Association (Tooth-brush Technique) |
| **ATE** | : AFTER -Training Experiment |
| **ATM** | : AFTER- Training Mode |
| **BTE** | : BEFORE- Training Experiment |
| **BTM** | : BEFORE- Training Mode |
| **f** | : frequency |
| **FDA** | : Food and Drug Administration |
| **Gx** | : The X- Axis of the Tooth Brush- Movement |
| **Gy** | : The Y- Axis of the Tooth Brush- Movement |
| **GYRO** | : Gyro- Scope |
| **Gz** | : The Z- Axis of the Tooth Brush- Movement |
| **LOG** | : Log Value |
| **MT** | : Manual Tooth Brush |
| **MOA** | : Multiphase Optimization Application |
| **MPM** | : Mechanical Physical Model |
| **MTB** | : Multidirectional Therapeutic Tooth Brush |
| **n** | : number of samples |
| **Nyl** | : Nylon |
| **OR** | : Oscilating Rotating |

| Abbreviations | Description |
|---|---|
| **AAC** | : Average Amplitude Coupling |
| **AVG** | : AVERAGE Over the Epoch length |
| **DASD** | : Difference Absolute Standard Deviation |
| **IDE** | : Integrated Development Environment |
| **MA** | : Mean of Amplitude |
| **MAV** | : Measures the Mean Difference Between Amplitudes |
| **MDF** | : Median Frequency |
| **MNF** | : Mean Frequency |
| **RMS** | : Root Mean Square |
| **SD** | : Standard Deviation |
| **SSC** | : Slope Sign Change |
| **VAR** | : Variance |
| **WAMP** | : Wilson Amplitude |
| **WL** | : Wavelet Length Power |
| **ZC** | : Zero Crossing |

# ÖZET

## DOKTORA TEZİ

### DİŞ FIRÇALAMA TEKNİĞİNİN PLAK TEMİZLEME BAŞARISI YOLUYLA ANALİZİ


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**Amaç/Amaç:** Ağız sağlığı kavramının temelini oluşturan ağız sağlığı düzeyleri ve diş sağlığı kalitesinin belirlenmesi üzerine odaklanmaktadır. Bu çalışma, çocuklar ve erken yetişkinlik döneminde diş fırçalama alışkanlığının öğrenilme sürecini netleştirmek amacıyla, diş fırçalama tekniklerinin kullanıldığı uygulamaların teknik ve fiziksel modeller aracılığıyla değerlendirilmesini hedeflemektedir. **Gereç ve Yöntem:** Veriler, 23 kişilik bir gruptan elde edilmiş olup, farklı yaş gruplarındaki kadın ve erkek bireylerden oluşmaktadır. Bu veriler, önerilen elektronik diş fırçalama ekipmanı ile X-Y-Z şeklinde üç farklı eksen yolunun kaydını içermektedir ve MATLAB tarafından bu üç eksenle ilgili kodlar çizilmek üzere işlenmiştir. **Sonuçlar:** Bu Çalışmada deneylerin öncesinde ve sonrasında doğru, MAV (6.00) ve WAMP (179.419) gibi genellikle azalan parametre değerleri, AAC (1.270) gibi genlikler arasındaki ortalamaların değiştiği Ölçülmüştür. Varyans (VAR) 78.829 ve sinyal-gürültü oranı, genlikler ve genlikler arasındaki ortalamaları gösterirken, MNF ve MDF (sırasıyla 0.071, 0.021) frekans bileşenlerindeki değişimi ifade etmektedir. Ayrıca, iki deney arasındaki tüm dönem uzunluklarının AVG'sinin ortalaması, hareket genliği azalması açısından %75 aralığında bulunmaktadır. Bununla birlikte, yapılandırılmış uygulamaya bağlı olarak iki deney arasında belirtilen değişiklikler vardır. Bu çalışma ile.

- Deneysel modelleme verileri arasında uyum sağlanmış ve plak birikimi ile diş lekelenmesinin azaldığı gösterilmiştir.
- Özel ihtiyaçları olan ve motor becerileri zayıf olan bireylerin diş fırçalama hatalarını düzeltmelerine yardımcı olmak amacıyla uygulama önerilmektedir, bu sayede uygulama bir eğitim aracı olarak değerlendirilmiştir.

**Tartışma:** Üzerinde durulan istatistiksel parametreler, deneklerin çoğunluğu için fiziksel hareket modelinin belirlenmesine yönelik özelliklerin çıkarılmasında kullanılmıştır. Veri işleme sürecinin tamamlanmasının ardından, önerilen elektronik ekipmanı kullanan 23 denek (eğitim aşaması öncesi ve sonrası) tarafından kaydedilen verileri gösteren istatistiksel değerler sunulmuştur. MNF ve MDF gibi bazı parametreler, deney öncesinden sonrasına doğru çoğu parametre değerinde azalma olduğunu göstermekte ve bu durum MAV, sinyalin genlikleri arasındaki ortalama farkı veya dalgalanma oranını ölçmektedir. Değerlerin azalması, kişinin dişlerini fırçalamayı öğrendiğini gösterir. Bu değer, kişinin hareketleri öğrendiğini gösterir ve ayrıca sunduğumuz yöntemin tıbbi gözlemlerinin başarısını takip edebilmemize olanak sağlar. Gx, Gy, Gz çıkışları, deneyler öncesinde ve sonrasında farklılık göstermektedir Önceden Gy yüksek genliğe sahip bir bölgeye sahiptir, fakat sonrasında bu bölge pürüzsüz hale gelmiştir:

- İki deney arasındaki ortalama değişim, hareket genliğini azaltarak %75 aralığındadır.
- Sonuçlar, deneklere diş fırçasının doğru kullanımının öğretilmesinden sonra modelimizin avantajlarını göstermektedir.
- Diş fırçasının hareket yönleri daha düzgün hale getirildi ve dişlere daha az zarar verilmiştir.
- öncesi ve sonrası deneyleri arasındaki genlik farkı, sonrasında deneylerinin rastgele hareketinin daha az olduğunu ve diş fırçasının doğru şekilde kullanılmasında daha kararlı olduğunu bize açıkça göstermektedir.

Deney, diş fırçalama hareketi yollarındaki düzensizliğin bakteri plağının kalıcılığına ve birikmesine karşılık geldiğini, hareket yollarındaki düzenlilik ve stabilitenin ise bakteri plağı birikiminin azaltılmasına ve kontrolüne karşılık geldiğini göstermektedir. Bu durum, önerilen elektronik diş fırçalama ekipmanına entegre edilen, diş hekiminin klinik değerlendirmesinin tedavi öncesi ve sonrası sonuçlarını yakalayan ve dolayısıyla fırçalama yönteminin kabul edilebilir veya kabul edilemez olduğunu gösteren uyarı sisteminin hassasiyetine bağlanmaktadır. **Çözüm:** Diş hekiminin gözlemlerinden elde edilen bulgular, kabul edilebilir veya kabul edilemez fırçalama metodunun ne olduğunu açıkça göstermektedir. Ayrıca, analitik veriler bize kişinin diş fırçalama tekniğindeki hareketleri öğrendiğini ve sunduğumuz yöntemin tıbbi gözlemlerinin başarısını net bir şekilde görebildiğimizi göstermektedir. Plak birikiminin önlenmesi ve ağız sağlığının korunması için daha fazla bilimsel araştırmanın yapılması gerekmektedir, bunun sağlıklı ve kaliteli bir yaşam için önemli olduğu görülmektedir.

Şubat 2024 , 145 sayfa.

**Anahtar kelimeler:** Ağız sağlığı, Plak temizleme, Elektronik cihaz, Çok yönlü, Diş fırçası

# ABSTRACT

## Ph.D. THESIS

### ANALYSIS OF TOOTHBRUSHING TECHNIQUE THROUGH PLAQUE REMOVAL SUCCESS

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**Background/aims:** Determining the levels of oral health, as well as the quality of dental health, are the keystone upon which oral health conceptions are built. This study aimed to assess teethbrushing techniques practices, using technical and physical model, in order to clarify the learning way of teeth brushing in children and pre-adults ages. **Materials and Methods:** Data through a group of 23 participants, males and females of different ages, has been recorded by the proposed electronic toothbrushing equipment of 3 types axes pathways of X- Y- Z. Detection, of the Before and After training Experiments, and been processed by MATLAB to plot codes for the three axes. **Results:** Through this study, most of the parameter values, such as the Mean Difference Between Amplitudes MAV (6.00), Wilson Amplitude WAMP (179.419), and Average Amplitude Coupling AAC (1.270) exhibit decreasing from the before to the after experiments, as the Variance VAR (78.829), and shown the mean differences between the amplitudes and the amplitudes of the signals rate, as the Mean Frequency MNF and Median Frequency MDF (0.071, 0.021 respectively) show the change in frequency components. Farthermore the average over all the epochs length**s** AVG between the two experiments, is in the range of 75% in aspects of movement amplitude reduction. **Conclusion**: The results from a dentist's observation, demonstrated what the acceptable or nonacceptable brushing method. Furthermore, analytical values show us that person learns the movements of teeth brushing technique, and from his /her medical observations, we can see clearly the success of the method we offer.
February 2024, 145 pages.

**Keywords:** Oral health, Plaque removal, Electronic equipment, Multidirectional, Toothbrush

# 1. INTRODUCTION

The history of the primitive tooth cleaning devices origins date back thousands of years [1]. Oral prophylaxis is the foundation of oral health, and daily plaque removal is considered important for oral health. As the ancient literatures reviewed that the primitive tooth cleaning devices origins date back thousands of years [1]. Toothpicks have a historical lineage dating back to prehistoric eras. The utilization of toothpicks was endorsed by the Greek sophist in the second century BC as a means to remove residual food particles. Additionally, evidence of toothpick usage has been found in the ancient Babylonian city of Ur, which thrived around 3500 BC, and the Romans also adopted the practice, employing wooden sticks typically measuring 5 to 6 inches in length. Chew sticks have been referenced in the literary works of Chinese, Babylonian, Greek, and Roman cultures dating as far back as 600 B.C.[2]. The modern iteration of the toothbrush traces its origins to 1498 A.D. in China, where it is said to have been crafted using hog bristles. The emergence of toothbrushes in Europe during the late 18th and 19th centuries featured variations made of materials such as gold, ivory, bone, and equipped with replaceable heads [1]. During the 1930s, economical manual toothbrushes featuring plastic handles and nylon bristles became readily accessible. Within the category of dental products, manual toothbrushes exhibit the most diverse range in terms of size, shape, texture, and design. A manual toothbrush typically comprises a bristled head and a handle. The inception of the first electric toothbrush dates back to 1939 [3]. Handles have been purposefully designed to ergonomically cater to various levels of dexterity, a feature particularly evident in toothbrushes intended for children, whose dexterity may not be fully developed. Furthermore, a study conducted in 1992 depicted and quantified the three-dimensional movements occurring during brushing, showcasing the bristle actions resulting from different brushing motions [4]. Over the past thirty years, power toothbrushes have been developed to enhance the elimination of food particles from the teeth. Multiple distinct technologies for power toothbrushes, each with varying modes of action, are currently accessible in the commercial market. As a result, tooth brushing has become an essential component of the daily regimen for the majority of individuals in industrialized nations, as they pursue both cosmetic and oral health advantages [1]. Both manual and powered toothbrush designs have prioritized the capability to access and cleanse interproximal tooth surfaces. Consequently, the tooth brushing behavior of individuals, encompassing factors such as force, duration, motivation, and motion, plays a crucial role in determining the efficacy of tooth brushing [5]. Announced that the dental professionals continue to emphasize the importance of improving brushing habits with patients.

As a result, they documented the following conclusion:

- Tooth brushing behavior modification is still a big challenge.
- Grip preference between individuals is inherent.
- Interaction is noticeable between the human hand and the toothbrush during there tooth brushing session [1].

Although a plaque staining agent remains the sole method for evaluating the efficacy of plaque removal through tooth brushing, dental professionals are not permitted to assess the brushing technique motion employed as a means of guiding patients in improving their tooth brushing skills [6].

Although many studies were done in various procedures that are used to evaluate the condition of the teeth after brushing by assessing the amount of the plaque layer removal.

Up to date, very few studies have investigated tooth brush techniques, and how to control the brushing technique motion used, to implement brushing methods correctly. Thus in this study we are going to discuss our brushing technique motion with electronic equipment which record the (Before and the After) results of a dentist's observation that shows what the acceptable or nonacceptable brushing method, while the tooth brushing techniques are considered the main factor for gaining good oral health.

## 2. CONCEPTUAL FRAMEWORK

However, the absence of a visible index to monitor patients' brushing movements presents a significant challenge for dental practitioners in objectively evaluating their patients' tooth brushing proficiency. While previous studies primarily focused on quantifying the removal of plaque layers, our research introduces a novel approach to assess the effectiveness and execution of toothbrushing techniques, recognizing the pivotal role of toothbrushing methods in oral and dental health care. Özgöz, Arabaci, Sümbüllü, & Demir examined the impact of handedness on tooth brushing abrasion, specifically investigating brushing habits in left- and right-handed adults. The study found no statistically significant variances between groups I and II based on their daily tooth brushing habits [7]. The seminal work by White, D., et al., pertaining to adult dental health data has documented significant shifts in the prevalence of oral conditions among British adults. A notable proportion of dentate adults, comprising 16% who frequently and 17% who severely experience adverse effects on their daily lives as a result of their oral health, are more likely to belong to a lower socioeconomic stratum and exhibit poorer clinical status with regard to caries and periodontal disease [8]. In their research on "Age Period Cohort Analysis of Toothbrushing Frequency in Finnish Adults," Raittio, E., et al., observed that, at the population level, positive shifts in toothbrushing practices were evident among adult Finns from 1978 to 2014 [9]. The aim of the study conducted by Ryu, M., et al., on "An Interprofessional Approach to Oral Hygiene" was to examine the impact of an interprofessional oral hygiene support program for elderly inpatients. The findings revealed that the implementation of the program led to a reduction in the microbial count on the tongue [10]. Aderinokun, G., et al., conducted an investigation into the suboptimal oral hygiene practices among school children in Idikan, Nigeria. In order to devise an effective strategy for enhancing the prevailing situation, the study encompassed a questionnaire survey and a focus group. The findings underscored the necessity of developing a health education package [11]. In their research, Flynn, P.M., et al., examined the validation of the unidimensional framework of the Oral Health Literacy Adults Questionnaire. The conclusions drawn emphasize the necessity for dimensionality investigations in populations characterized by low levels of Oral Health Literacy (OHL) [12]. Ihab, M., et al., employed m-Health strategies to encourage mothers to facilitate the tooth brushing of their preschool children. The evaluation of behavioral change will be based on the percentage reduction in the dental plaque index of children after a period of 6 months, as well as the self-reported frequency of tooth brushing by the mothers. The outcomes of this investigation hold the potential to inform the development of refined interventions for behavior modification utilizing Health and MI methodologies [13]. Patel, J., et al., deliberated on the determinants influencing oral hygiene behavior in patients diagnosed with moderate and severe chronic periodontitis, as per the theory of planned behavior. The investigation concludes the assessment of psychosocial determinants of oral hygiene behavior in patients with periodontitis, emphasizing the significance of patient-centered preventive oral health care education [14]. Ni Riordain, R., et al., have established a comprehensive set of patient-centered outcomes for adult oral health, known as the Adult Oral Health Standard Set (AOHSS), through an international, cross-disciplinary consensus. In summary, employing a rigorous methodology, a uniform core set of oral health outcome measures for adults, with a specific focus on caries and periodontal disease, has been formulated for application in clinical practice, research, advocacy, and population health initiatives [15]. Xu, M., et al., have identified factors linked to the utilization of oral health services among adults and older adults in China. The findings of the study indicate that adults aged 35-44 years who were female, exhibited sound oral health knowledge and attitudes, and perceived their oral health status as fair. Furthermore, older adults who availed oral health services tended to be female, have coverage under Urban Resident Basic Medical Insurance or government medical insurance, possess a higher level of education, fall within the 2nd income tertile, and perceive their oral health status as poor or very poor [16]. Ramroop, V., et al., presented an analysis of the knowledge, attitudes, and behaviors regarding preventive oral care in early childhood among pediatricians in Trinidad and Tobago. A prevalidated questionnaire was distributed via SurveyMonkey to 70 out of 75 pediatricians registered with the Medical Board of Trinidad and Tobago for whom email addresses were obtainable through a national survey. The outcomes revealed positive attitudes among pediatricians in Trinidad and Tobago regarding oral health. However, their understanding of oral disease prevention, encompassing the application of fluoride and the timing of the initial dental visit, appears to be insufficient [17]. In their investigation of the oral health practices of individuals residing in urban and rural regions of Burkina Faso, Africa, Varenne, B., et al. observed significant correlations between high incidence of dental caries and the consumption of soft drinks and fresh fruits among 12-year-olds. The findings suggest the need for health authorities to prioritize the reinforcement of oral disease prevention and health promotion initiatives over conventional curative interventions [18]. Bowyer, V., et al. conducted a study on the awareness of oral health among adult patients with diabetes, revealing that a significant number of these individuals lack sufficient understanding of oral care and the associated health complications related to diabetes. Furthermore, the study indicates that healthcare professionals provide limited guidance on this matter. The authors recommend the implementation of training and guidance for both healthcare professionals and patients regarding the significance of maintaining good oral health in individuals with diabetes [19]. Gunaki, S., et al. conducted a study on the development and assessment of a polyherbal toothpaste. The study involved formulating a toothpaste containing plant extracts derived from (pods), (leaves), and (gum resin). The formulation was subjected to in vitro analysis and physical examination to assess parameters such as color, odor, taste, uniformity, pH, spreadability, foaming characteristics, moisture content, and stability. The preparation of the polyherbal toothpaste was carried out using the trituration method [20]. Myint, Z.C.K., et al. conducted a study to identify risk indicators for dental caries and gingivitis among 10−11-year-old students in Yangon, Myanmar. The research aimed to gather fundamental data on the dental caries and gingival status of students in Myanmar, as well as to pinpoint associated risk indicators, encompassing socioeconomic circumstances and oral health practices and habits. The findings revealed a notable prevalence of dental caries and gingivitis among the students in Myanmar, with socioeconomic status, oral hygiene, and oral health behaviors identified as significant risk indicators [21]. De Oliveira, L.V., et al. conducted a cross-sectional study focusing on the self-perception of teeth alignment and color among adolescents. The study aimed to assess the prevalence and determinants associated with the self-perception of teeth alignment and color in this demographic. The research involved a representative sample of students aged 15 to 19 years. The study's outcome centered on the self-perception of teeth alignment and color, as determined by selected items from a structured and validated questionnaire (the Child’s and Parent’s Questionnaire about Teeth Appearance). The findings indicated that adolescents with highly educated mothers exhibited a lower prevalence of negative self-perception compared to those with mothers with a lower level of education [22]. Ageeh, H.N., et al. conducted a cross-sectional study examining the impact of Applied Behavior Analysis (ABA) on enhancing knowledge of oral hygiene practices among cooperative autistic children in Jazan, Saudi Arabia. The study aimed to evaluate the effectiveness of ABA, utilizing avatars and video-based delivery methods, in improving the understanding of oral health hygiene among cooperative autistic children. The conclusion drawn from the study indicates that the application of ABA through avatars and video delivery significantly enhances knowledge regarding oral health hygiene among these children [23]. Olusile, A.O., et al. undertook a study focusing on the self-assessment of oral health status, utilization of oral health services, and oral hygiene practices among adult Nigerians. The research revealed that adult Nigerians utilize a limited number of oral health services. The study suggests the need for further research to identify additional factors influencing oral health behavior in this demographic [24]. Luker et al. conducted a quantitative assessment of the correlation between hand arm motion and thumb force, revealing significant associations between these variables. Consequently, the shoulder and wrist play crucial roles in facilitating finger and hand brushing motion. However, the specific reasons for the differing contributions of the shoulder and wrist joints in right and left side brushing remain unclear [25]. Kalsi et al. conducted a study to assess the supplementary effectiveness of the Sensodyne Expert toothbrush compared to other commonly utilized commercially available toothbrushes. The study exclusively involved right-handed subjects. The findings indicated that the plaque removal efficacy of the Sensodyne Expert toothbrush was similar to that of other toothbrushes when evaluating the remaining plaque on the designated teeth after brushing [26]. Ng, Tsoi, & Lo examined and analyzed the narrative, aiming to comprehensively evaluate the powered toothbrush in terms of design, safety, and application. The review encompassed aspects such as tufts, filaments, handles, mechanics, motions, and materials interactions based on a range of available sources. The rotational design was recommended as being clinically more effective than the manual one, and it was noted that certain contemporary models may incorporate oscillation tufts heads, potentially offering benefits for patients with specific needs [27]. Iyer et al. highlighted the effectiveness of plaque removal associated with the Colgate 360 Whole Mouth Clean Toothbrush in their clinical investigation. The study involved participants aged 18 to 45 years, each possessing a minimum of 20 permanent teeth without any prosthetic crowns. The findings of the study indicated a notable decrease in plaque scores over the course of the study period with the consistent use of the Colgate 360 Whole Mouth Clean Soft Toothbrush [28]. Hapsari & Hunsrisakhun conducted a study comparing the efficacy of plaque removal and gingival improvement between the Modified Circular method and natural tooth brushing in 10 to 12 year-old children. This quasi-experimental study involved 124 fifth graders who were randomly assigned to either the control or intervention groups. The findings indicated that the Modified Circular method is more effective in removing plaque in 10 to 12 year-old children compared to the natural tooth brushing method [29]. The research presented by Bindayel et al. aimed to investigate the prevalence of electric toothbrush (ETB) usage and explore the contributing factors among Saudi adults. This involved conducting personal interviews with 505 randomly selected Saudi adults in Riyadh city. The findings revealed that less than a quarter of the sample had utilized ETBs, with only 5.7% maintaining consistent use.

The observed low frequency of ETB usage suggests a potential lack of emphasis by clinicians on the benefits of ETBs [30]. The objective of the systematic review analysis conducted by Vibhute & Vandana was to assess the efficacy of manual and powered brushes in terms of plaque and gingival health, as well as stain removal. The inclusion criteria for the review required that the trials be randomized controlled trials comparing manual and powered brushes. Overall, the review found no statistically significant evidence of a difference between the effectiveness of powered and manual brushes [31]. The study initiated by Kallar et al. aimed to outline, assess, and juxtapose the effectiveness of manual and powered toothbrushes in both supervised and unsupervised settings among a cohort of 200 school children. It was observed that all types of toothbrushes led to a notable decrease in plaque accumulation, albeit to varying extents. Notably, powered toothbrushes exhibited a significant reduction in plaque compared to manual toothbrushes. Furthermore, when utilized under supervised conditions, both types of toothbrushes demonstrated a greater reduction in plaque accumulation [32]. Neelima et al. highlighted the effectiveness of mechanical plaque removal, specifically noting the designed benefits of powered toothbrushes for individuals with disabilities. There is a scarcity of literature comparing the plaque removal efficacy of manual and powered toothbrushes among differently abled individuals. The study compared the plaque removal efficacy of a battery-operated powered toothbrush with that of a manual toothbrush after a single brushing on the 8th day. The findings indicated that manual toothbrushes were equally effective compared to powered toothbrushes in this context [33]. Based on a publication by Bhimani et al., an innovative ergonomic toothbrush was developed and its oral hygiene efficacy was compared with that of a standard commercial toothbrush. The study also aimed to evaluate and compare the satisfaction and comfort levels associated with both types of toothbrushes among the 60 subjects. The questionnaire responses indicated that the novel toothbrush elicited greater satisfaction, comfort, and oral hygiene benefits compared to the standard commercial toothbrush [34]. Sehmi & Olley examined the impact of tooth brushing force on alterations in dentine tubule patency using an erosion toothbrush abrasion model. A total of 60 dentine samples, each prepared with an artificial smear layer, were randomly allocated to control (no toothbrush), 100 g, 200 g, or 400 g toothbrush groups. Subsequently, they were immersed in a 3:1 artificial saliva solution. It was found that at higher brushing forces (400 g), a greater number of dentine tubules were exposed [35]. In their investigation, Turssi et al. addressed the influence of toothbrush bristle configuration and brushing load on the development of non-carious cervical lesions. Human premolars, affixed to acrylic blocks, were subjected to brushing under loads of 1N or 3N using one of the following toothbrush types: 1) rippled Oral B Contour, 2) ordinary flat trimmed Oral B Indicator, 3) cross-angled rubber bristles Oral-B Pro Health, 4) cross-angled flexed head Oral-B Pro-Flex, and 5) feathered Oral-B Compact Clean. It was observed that the toothbrush with the ordinary flat trimmed bristle arrangement exhibited higher abrasiveness, whereas the feathered toothbrush resulted in fewer wedge-shaped lesions [36]. S. Singh, et al. conducted a study to assess the impact of three distinct bristle designs (Zig zag-wavy, Flat trim) of manual toothbrushes on plaque removal. The study was conducted in a manner that kept the investigators blind to the details. Three different types of commercially available manual toothbrushes were evaluated. The findings of this investigation indicate that the three different bristle designs of manual toothbrushes led to a notable reduction in plaque scores from baseline levels. However, no significant variances were observed between the three groups [37]. The objective of this provided investigation by Checchi et al. was to assess the perceived quality of rounded filaments in various toothbrush brands and to ascertain whether manufacturers' claims of quality standardization are substantiated. The evaluation encompassed the testing of 2 samples of medium hard nylon toothbrushes from 31 different types available in the retail market in Italy. The outcomes suggest that a significant proportion of toothbrushes available in the retail market fail to meet acceptable quality criteria [38]. Based on a publication by Putt et al., the objective was to compare the safety and effectiveness of two non-rechargeable battery-operated power toothbrushes, namely the Braun Oral B Battery toothbrush and the Colgate Act brush. The study involved 114 participants from the general population. The investigation revealed no substantial evidence of oral soft or hard tissue trauma, and both toothbrushes were deemed safe for use when utilized in accordance with the manufacturers' instructions [39]. angade et al. addressed the limited literature available on the recommended frequency for replacing toothbrushes. Consequently, this research sought to examine the influence of Progressive Toothbrush Bristle Flaring on the effectiveness of plaque control using a toothbrush. Thirty-six subjects were randomly chosen and received comprehensive oral prophylaxis 10 days before the baseline plaque assessment. The findings revealed a progressive rise in plaque scores corresponding to the increase in toothbrush bristle flaring [40]. The investigation conducted by Balasubramaniam, Diwakar, and Brinda sought to identify the factors influencing the choice of manual toothbrush among an urban population for the purpose of oral health maintenance. A survey involving 1000 participants aged 18 and above, who frequented business malls, departmental stores, and cooperative society stores in Chennai city, was undertaken for this purpose. The findings of the study highlight the significant influence of consumers' education, occupation, and income on their selection of toothbrush [41]. Chand and Solanki conducted a study to evaluate the efficacy of toothbrushes with and without the use of dentifrice in removing debris and plaque among hostel inmates aged 20-24 years. A randomized clinical trial involving 30 undergraduate students from K.D. Dental College and Hospital was conducted, with the study groups instructed to adhere to the modified bass technique. The findings of this investigation demonstrate that the utilization of dentifrice significantly enhanced the cleaning efficacy of the toothbrush in removing debris and plaque compared to using the toothbrush without dentifrice [42]. The objective of the research conducted by Patel et al. was to clinically assess the impact of miswak as a supplement to tooth brushing on plaque levels and gingival health in individuals diagnosed with mild to moderate chronic generalized marginal gingivitis, in comparison to those who solely used toothbrushes. The study revealed a notable enhancement in plaque score and gingival health when miswak was employed as an adjunct to tooth brushing [43]. As investigated by Malik et al., this study aimed to compare the efficacy of two oral implements, the Chewing stick and the manual toothbrush, in terms of plaque removal and impact on gingival health. The sample size was determined in accordance with the guidelines of the American Dental Association. Participants were randomly assigned to two interventional groups and given either chewing sticks or toothbrushes. The findings indicated that the Chewing stick demonstrated comparable, and at times superior, mechanical and chemical cleansing of oral tissues in comparison to a toothbrush [44]. In their study, Warad et al. sought to analyze and evaluate the effectiveness of plaque removal using two manual toothbrushes with distinct bristle designs among female clinical undergraduate students in Virajpet. A randomized clinical trial spanning 5 days was conducted to compare the efficacy of two manual toothbrushes featuring round and zig-zag bristles of medium stiffness. The results indicated that there was no significant disparity in the mean values of plaque removal efficacy between the round and zig-zag bristle toothbrushes [45]. Erbe et al. conducted a study with the aim of evaluating the effectiveness of plaque removal and motivation when comparing a manual toothbrush to an electric power toothbrush among orthodontic patients. Sixty adolescents with fixed orthodontic appliances in both arches were randomly assigned to the study groups. The findings revealed that the use of an interactive power toothbrush resulted in longer brushing times and significantly greater plaque removal compared to the use of a manual brush [46]. The study conducted by G. Singh et al. aimed to clinically evaluate and compare the effectiveness of sonic and ionic toothbrushes. A single-blind study utilizing a split-mouth method was carried out over a period of 45 days, assessing plaque, gingival, and bleeding indices. The findings of the study suggest that, although the sonic toothbrush demonstrated a marginally superior performance compared to the ionic toothbrush, the difference was not statistically significant [47]. The study conducted by Veiga et al. sought to ascertain the prevalence and evaluate the standard of oral health behaviors among a cohort of Portuguese adolescents aged 12 to 19 years, with the aim of examining their correlation with socio-demographic factors. The findings suggest that enhancing oral health education within schools should be contemplated as a means to mitigate the risk of oral diseases and foster improved oral health behaviors [48]. Lucas et al. conducted a study with the objective of determining the prevalence, strength, and microbial composition of bacteremia linked to tooth brushing. The study encompassed 141 children and adolescents, aged 3 to 17 years. The findings indicated that tooth brushing often leads to a statistically significant increase in bacteremia compared to baseline levels. It was concluded that tooth brushing plays a significant role in the accumulation of dental bacteremia [49]. Lin, Chuang, & Chang highlighted a technique for dental plaque removal involving the use of a tooth tray with micro bubbles and subsequently confirmed its cleaning effectiveness through experimentation. A cleaning apparatus generating micro bubbles (Braun MD20) was employed in the study to investigate the impact of these variables on dental plaque removal. The study revealed that the influence of control variables on plaque removal was notably more substantial than that of intermediate variables, with the nozzle dimension demonstrating a significant effect on plaque removal at a 0.05 significance level [50]. The research conducted by Alshehri sought to evaluate the understanding and mindset of Saudi individuals regarding self-perceived halitosis. A cross-sectional survey involving Saudi adults and an 18-point self-administered questionnaire were utilized for this purpose. It was observed that enhancing patients' awareness of the causes of oral malodor could potentially alleviate their concerns about halitosis. Furthermore, the study indicated that patients' complaints of oral malodor can significantly impact their self-confidence and social interactions with others [51]. In their investigation, Lawal et al. examined and evaluated oral health education programs in schools carried out by the Community Dentistry Unit of a tertiary hospital in a prominent city in Nigeria. The study demonstrated the viability of cost-effective oral health education and the readiness of schools to partake in such initiatives. The research also identified communication barriers that, if addressed, could enhance the effectiveness of school oral health education programs in resource-constrained environments [52]. Alshehri undertook a study to delineate the association between the oral health of young children and that of their mothers. Leveraging data from the Third National Health and

Nutrition Examination Survey and an associated linked birth certificate file, the researchers assembled a cohort of 1,184 mother-child pairs, encompassing children aged 2 to 6 years. The study revealed that the oral health status of mothers serves as a robust predictor of the oral health status of their children [51]. Ogunrinde et al. conducted a study to evaluate the dental care knowledge and practices of secondary school adolescents in the Ibadan North Local Government Area of Oyo State, Nigeria. The assessment involved 412 secondary school adolescents who were surveyed using an interviewer-administered questionnaire. The study highlighted the consumption of sticky, sugary, and chocolaty food items. It was observed that while the majority of the respondents exhibited good oral health knowledge, their dental health practices were found to be lacking [53]. This research conducted by Peeran et al. examines the impact of varying educational levels on self-reported oral practices among young adults in Jizan. The survey was carried out in four areas surrounding the University of Jizan, involving respondents aged between 15 and 34 years who completed a self-administered, structured questionnaire. Intergroup comparisons were performed using the Chi-square test. It was observed that individuals with lower education levels and illiterates tend to engage in detrimental oral practices [54]. A cross-sectional examination was conducted by Austregésilo et al. involving a sample of high school students from state public schools in Sao Lourenco da Mata, State of Pernambuco, Brazil (n = 1154). The analysis identified a second cluster characterized by the concurrent consumption of high amounts of bread, pasta, and snacks, high intake of sweets, high consumption of soft drinks, and low intake of fruits and vegetables. This led to the conclusion that the first cluster primarily exhibits behaviors associated with increased risk [55]. Maldupa et al. conducted a study in Latvia to investigate potential risk indicators and the severity of caries prevalence. A cross-sectional national survey of oral health among 12-year-old children was carried out in 2016. The study revealed a notably high prevalence and severity of caries among 12-year-old children. Furthermore, it was observed that there has been a substantial decrease in the prevalence of dental caries in Western European countries [56]. In a cross-sectional study devised by Salama et al., the research aimed to compare the tooth brushing practices reported by Saudi children and their parents, and subsequently assess the level of agreement between these reports. The study involved a sample of 100 Saudi parents and their children aged 8–12 years. The findings indicated a degree of agreement between the reported tooth brushing practices of the children and those reported by their parents [57]. Numerous researchers, including Jürgensen & Petersen, have examined the rising prevalence of dental caries among children in low-income countries, with a notable increase observed in

12 year olds, posing potential adverse effects on children's well-being. Limited data is available on the oral health status of these children. It was found that children with a positive or moderate perception of their own oral health exhibited a low risk, while semi-urban children and boys showed a high risk of gingival bleeding [58]. Cantoral et al. conducted an investigation to explore the correlation between dietary fluoride intake, overall carbohydrate consumption, and other significant dietary factors with the occurrence of dental caries among adolescents. The study revealed that increased total carbohydrate intake and the frequency of consuming sugary foods were linked to a higher incidence of dental caries, without any discernible threshold for these effects [59]. Veiga et al. developed a cross-sectional study involving a cohort of 447 adolescents ranging from 12 to 19 years old, who were enrolled in a public school in Portugal. Based on the findings of this study, it is recommended that oral health community programs and primary preventive measures, including enhanced oral health education in schools, should be implemented to diminish the risk of oral diseases and foster improved oral health practices [48]. Al Subait et al. initiated a study to evaluate the extent and dimensions of knowledge, attitudes, and practices pertaining to oral health among school students who participated in a prominent festival in the City of Riyadh. This survey was conducted using a cross-sectional study design, and the study participants were randomly selected from among Saudi national students. The findings revealed that approximately two-thirds of Saudi youth engage in tooth brushing, a proportion that aligns with reported rates among comparable age groups a decade ago [60]. The objective of the research conducted by Soroye et al. was to evaluate the oral health behaviors of secondary school students in Lagos State, Nigeria, and explore the impact of oral hygiene practices on the occurrence of dental caries. Questionnaires were distributed, and dental assessments were performed on a sample of 598 school children aged 11–20 years. The study revealed that the oral health practices of the participants were deemed unsatisfactory [61]. Viswanath et al. conducted a study with the objective of investigating the impact of various sugar types, as well as the frequency of sugar consumption and oral hygiene habits, on the prevalence of dental caries among school children of both genders, aged 5 to 11 years, in the Bangalore North region. A specifically tailored questionnaire was employed to gather data regarding the types of sugar consumed. The findings indicated a clear correlation between the frequency of sugar intake and the occurrence of dental caries, while regular tooth brushing practices were shown to mitigate the severity and prevalence of dental caries [62]. The research designed by Veiga et al. sought to determine the prevalence of dental caries through a cross-sectional study involving 605 children, aged 6 to 12 years, from 27 public schools in Portugal.

Dental caries were evaluated through intraoral examinations, revealing a substantial prevalence of dental caries in younger children, with a notable proportion exhibiting multiple instances of dental caries [63]. Deinzer et al. underscored the significance of providing oral health education to children and adolescents in order to equip them with the necessary knowledge to maintain proper oral hygiene as they transition into adulthood. Meanwhile, Liu et al. conducted a study to document the knowledge, attitude, and behavior of family caregivers and to identify the pertinent factors influencing their efforts in promoting oral health among children, aged 6 to 12 years old, with disabilities in 10 special schools. It was observed that favorable oral health behavior was notably linked to a higher level of education, improved knowledge, and a positive attitude [64]. As indicated in the research conducted by Otsuka et al., it was established that the manual toothbrush is the predominant tool used for home-based plaque control. The corresponding author, from the Department of Translational Research at Tsurumi University School of Dental Medicine in Yokohama, Japan, noted that manufacturers have endeavored to enhance plaque removal efficacy by refining the design of manual toothbrushes. In 2018, 26 commercially available toothbrushes from the Japanese market were selected for evaluation. The findings of this study revealed that the use of solely commercially available manual toothbrushes was not directly suitable for interproximal cleaning [65]. The objective of this study, conducted by Austregésilo et al., was to assess the clustering of seven categories of general and oral health risk behaviors among adolescents. A cross-sectional analysis was carried out using a sample of high school students from state public schools in São Lourenço da Mata, State of Pernambuco, Brazil (n = 1154). The identification of clustered behaviors holds significant implications for the development of comprehensive strategies in health promotion policies and practices [55]. The aim of the study conducted by Deinzer et al. was to evaluate the oral hygiene proficiency of the participants through observation. Consequently, the comparability of the cohorts seems sufficiently strong to warrant some inference regarding the significance of the instruction to perform oral hygiene to the best of one's abilities in contrast to customary oral hygiene practices. The observed behavioral deficiencies suggest a lack of motivation for oral hygiene rather than inadequacies in the ability to perform oral hygiene tasks [66]. Kuwabara et al. conducted this study to investigate whether infrequent tooth brushing is an autonomous risk factor for DM and DL using a follow-up approach. This retrospective cohort study was carried out at St. Luke’s International Hospital in Tokyo, Japan. The findings suggest that tooth brushing practices may offer benefits in mitigating the risk factors associated with the development of cardiovascular disease [67]. The primary aim of the study outlined by

Melo et al. was to assess the influence of a 21- day school program on the oral health of children. A secondary objective was to evaluate its impact on knowledge, behavior, and tooth brushing habits. The study encompasses infant and junior schools in Indonesia and Nigeria, with the goal of enlisting 20 schools, each with children aged 6 to 9 years, in both countries. The data collection is anticipated to take place throughout 2019, and the study's findings are expected to be published by March 2020 [68]. The objective of the study advanced by da Silva et al. was to assess the impact of simulated tooth brushing over a period of ten weeks on the surface roughness and optical properties of resin-based composites (RBCs). The roughness, color, translucency, and gloss of each RBC were gauged before and after immersion in distilled water (DW) and propionic acid (PA) for ten weeks. The results indicated that tooth brushing heightened the roughness and reduced the gloss of the three RBCs, while the translucency remained unaffected by the tooth brushing process [69]. Kakar et al. conducted a comparative clinical study aimed at assessing the comparative effectiveness of commercially available manual toothbrushes in enhancing periodontal health. The study revealed that a manual toothbrush equipped with angled, Criss Cross® bristles demonstrated notable advantages over other toothbrushes. Healthy adult participants from 24 dental institutions across India were enlisted and provided with the manual toothbrush featuring angled bristles for use. This uncontrolled real-world study observed enhancements in oral health and hygiene subsequent to the use of the manual toothbrush with Criss Cross bristles over a 12 week period [70]. Dhir & Kumar et al. conducted a study with the aim of comparing the effectiveness of a powered toothbrush and a manual toothbrush in relation to periodontal and microbial parameters. A total of 120 participants were chosen and allocated to either the power toothbrush group, which utilized the Oral-B® Criss Cross® model, or the control group, which used the Oral-B® manual toothbrush. The study's findings indicated that the oscillating rotating technology featured in the electric toothbrush yielded statistically significant outcomes compared to the manual toothbrush, establishing its safety and effectiveness for long-term use [71]. The study conducted by researcher Kulkarni et al. aimed to evaluate the efficacy of a powered toothbrush (Braun-Oral-B) and a manual toothbrush (Oral-B40) in terms of supra-gingival plaque area and gingival health. A cohort of 45 patients aged 19 to 23 years was enrolled in the study. While both groups initially exhibited similar conditions, individuals using a powered toothbrush demonstrated superior results compared to those using a manual toothbrush when assessed at the fourth week [72]. In their article, Sharma et al. conducted a comparison of the safety and efficacy of plaque removal between two oscillating, rotating, pulsating toothbrushes (Oral-B Professional Care™

7000 and Oral-B 3D Excel) and a high-frequency toothbrush (Sonicare ® Advance, Philips Oral Healthcare) in a single-use, examiner-blind study. Subjects underwent an oral tissue examination, and the study concluded that the action of the oscillating, rotating, pulsating toothbrushes (Oral-B Professional Care 7000 and Oral-B 3D Excel) was more effective in removing plaque than the high-frequency toothbrush [73]. In a trial study conducted by Erbe et al., the effectiveness of plaque removal and the assessment of motivation were compared between a manual toothbrush and an interactive power toothbrush in orthodontic patients. The study involved sixty adolescents with fixed orthodontic appliances, who were instructed to brush unsupervised using either an interactive power toothbrush (Oral-B Professional Care 6000, D36/EB20) with Bluetooth technology or a regular manual toothbrush (Oral-B Indicator 35 soft). The results indicated that the interactive power toothbrush led to increased brushing times and significantly greater plaque removal compared to the manual brush [46]. Al-Hammadi et al. initiated a study aimed at evaluating the oral health knowledge, behavior, and practices associated with the use of miswak (chewing stick) among the population of the Aseer Region, with a specific focus on assessing awareness of oral hygiene techniques. The predominant oral hygiene method observed in our study is the utilization of a toothbrush, often complemented by the use of miswak [74]. Lewis & Dwyer Joyce highlighted the utilization of microscopy images to infer the deflection and traction of filaments, as well as the entrapment of particles by these filaments and their abrasive action on the surface. These investigations contributed to the formulation of qualitative and quantitative models pertaining to the mechanism by which material is eliminated during dental cleaning. The quantitative model incorporates several empirical factors by necessity; nevertheless, its predictions demonstrate favorable alignment with in vitro wear outcomes documented in the literature [75]. The aim of this study conducted by Terrana et al. was to compare the efficacy of plaque removal between a triple headed toothbrush and a traditional manual toothbrush in adolescents with fixed orthodontic appliances. Participants were instructed to brush once using either a conventional manual toothbrush or a triple headed toothbrush. The findings of this investigation present compelling evidence that the triple headed toothbrush yields a notably reduced plaque index in comparison to the conventional manual toothbrush following brushing [76]. Vajawat et al. endeavored in their study to assess the effectiveness of powered toothbrushes in enhancing gingival health and reducing salivary red complex counts in comparison to manual toothbrushes among individuals with autism. A cohort of forty autistic individuals was chosen, with the test group receiving powered toothbrushes and the control group receiving manual toothbrushes.

The findings indicate that powered toothbrushes lead to a substantial overall enhancement in gingival health when consistent reinforcement of oral hygiene instructions is provided [77]. Inada et al. addressed the imperative for professionals to provide guidance on brushing techniques, including the coordinated movements of the shoulder during brushing on the right side and the wrist during brushing on the left side (both buccal and palatal). This underscores the importance of indicating adjustments in the appropriate positioning of the toothbrush for thorough tooth cleaning [25]. To conduct a comparative evaluation of a new oscillating rotating (O-R) electric rechargeable toothbrush with micro vibrations (Oral-B ion) against a manual toothbrush in terms of reducing gingivitis and plaque. The effectiveness was measured at the outset. The innovative O-R electric toothbrush with micro vibrations yielded notably greater reductions in plaque and gingivitis compared to a manual toothbrush, with performance advantages evident after just one brushing session and persisting throughout the 8 week assessment period [78]. The approach introduced by Korpela et al. in their publication, employed for assessing tooth brushing efficacy using audio data captured by a smartphone, involved the classification of segments of the data into distinct categories based on the brushing location and type of brush stroke. This novel method for evaluating tooth brushing performance by solely utilizing audio data from end users facilitates a straightforward means for users to assess their tooth brushing with minimal effort overall [79]. Wolf et al. presented an inquiry into tooth brushing behaviors, which is a crucial avenue for comprehending their impact on brushing efficacy. The MT system was utilized to ascertain the position and orientation of a toothbrush in relation to the jaw as subjects brushed under realistic conditions, thereby shedding light on the implications of tooth brushing habits [80]. Tosaka et al. have illustrated the efficacy of examining tooth brushing cycles through a system that gauges tooth brushing motion using an accelerometer and tooth brushing force using a strain tension gauge affixed to a toothbrush. They noted that tooth brushing movement and brushing force vary depending on the brushing position. Their findings suggest the significance of further exploration in this area [25]. Adam, R., et al., in their research, presented an evaluation of the plaque removal efficacy of a recently developed oscillating-rotating electric rechargeable toothbrush with micro-vibrations in comparison to a manual toothbrush. Their findings indicate that the innovative O-R toothbrush with micro-vibrations yielded notably superior plaque reductions when compared to the manual toothbrush [81]. Adam, R.J., et al., presented the Oral-B iO electric toothbrush, featuring next-generation oscillating-rotating technology, in their study. The device directs motor energy directly to the bristle tips and incorporates a redesigned round brush head and smart pressure sensor to improve plaque removal and promote proper brushing technique. The study's conclusions highlight that this specially designed oscillating-rotating electric toothbrush with a linear magnetic drive demonstrates significantly greater plaque removal and gingival health benefits, along with additional features aimed at enhancing the brushing experience and clinical outcomes [82]. Otsuka, R., et al., conducted a study on the properties of manual toothbrushes that influence plaque removal from the interproximal surface in vitro. They noted a limited number of papers available on the interproximal cleaning efficiency of manual toothbrushes when used independently. The objective was to assess the effectiveness of commercially available toothbrushes on interproximal cleaning and identify the key properties that contribute to differences in performance. A modified scrubbing technique was utilized to remove the plaque. The study revealed that attention should be directed towards toothbrush properties to improve plaque removal from the interproximal surfaces [65]. Recent research has demonstrated that young adults continue to exhibit a limited capacity for plaque removal [66]. Several studies have been performed to study accomulation factors of plaque removal, while limited studies focused on the basics of tooth brushing techniques methodology, however this study investigate the teeth brushing technique methodology.

# 3. MATERIAL and METHODS

3.1 Modelling of electronic equipment

The proposed electronic equipment (Multidirectional Therapeutic Tooth Brush), is to be introduced as an analytical application, that has been configured to act as a monitoring application, including and directing 3 types of axes x- y- z, to provide analytical data of the tooth brush movements during brushing procedure according to ADA brushing method. This is because biting subjects tooth to a trifecta critical stress compressive, or tensile, which can lead serious damage [54]. Thus could contribute the release of huge obstacle of the inherent hand grip, since it is important that the handle in which the devices are held or mounted have to be easy and comfortable to grip [55]. That's to follow up, stabilize, and regularize toothbrush motions, in the equilibrium position as in Figure (3.1).

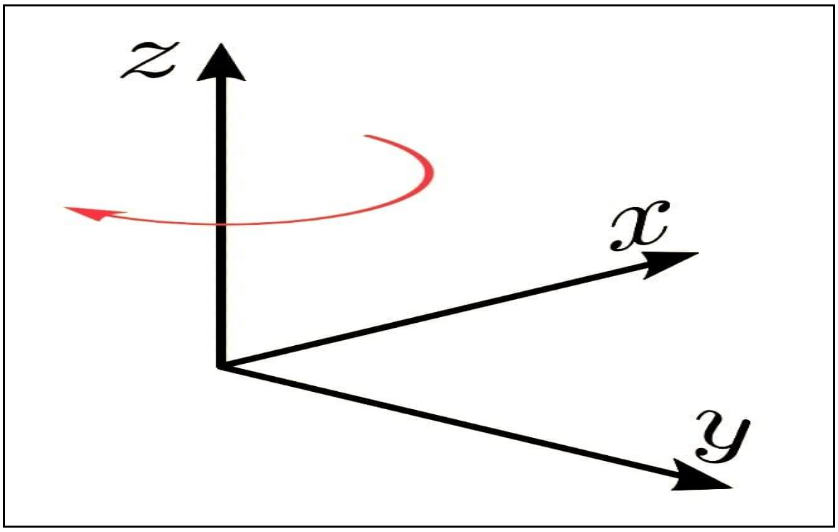


Figure 3.1: 3 types axes of X-Y-Z of toothbrush motion in the equilibrium position [57]

The m-controller represents is an open-source software solution rooted in Arduino technology, providing opportunities for reprogramming and reconstruction [57]. The Arduino Nano facilitates the use of breadboards, making it well, suited for mini-projects, as shown in the Figure (3.2) below.

### 3.1.1. Arduino Hardware

The hardware composition of the Arduino developmental board comprises multiple components, each contributing to its overall functionality. The components are as follows:

**Micro Controller**

The memory of the developmental board functions akin to a miniature computer, capable of processing data and issuing commands to connected devices.

**External Power Supplies**

This power supply is employed to furnish the Arduino development board with a regulated voltage, typically within the range of 9 to 12 volts.

**USB plug in**

The connector functions as a crucial input for the board, allowing the program for the M-controller to be uploaded via USB.

**Inter Programmer**

The micro USB port on the M-controller enables the transfer of programmed software to the device without requiring a distinct programmer.

**Pinout of Analog**

The board features analog input terminals, to which analog output can be interfaced.

**Pinout of digital I/O**

The board is equipped with pins designated for digital input, facilitating digital input/output operations [57].

**Pining out of GND and it's Power**

The experimental development board includes pins providing approximately 3.3 volts or 5 volts of electrical potential as shown in the Table (3.1).

Table 3.1: The Arduino Nano- Technical specifications [57].

| Pin-No. | The-Name | The-Type | The-descriptions |
|---|---|---|---|
| 1-2,5 to 16 | d-0-d-13 | I- O | digital input and output ports spanning from 0 to 13 |
| 3, 28 | reset | In-put | active-low functionalities are incorporated |
| 4, 29 | gnd | pwr | Ground- supply |
| 17 | 3-v-3 | out-put | +3.3V out-put |
| 18 | aref | in-put | Reference- adc |
| 19 to 26 | a-7 a-0 | in-put | The board supports analog input across channels 0 through 7 |
| 27 | +5V | out-put | The board features regulator for +5V output |
| 30 | vin | pwr | volts- supply |

### 3.1.2. Pining Layout of Arduino Nano

The Nano has the following configuration:

- The board offers 8 analog inputs, each providing 10 bits of resolution (equivalent to 1024 different values). By default, these inputs measure from ground to 5 volts, although it is feasible to adjust the upper end of their range using the analog reference function.
- Analog pins 6 and 7 are restricted from use as digital pins, and certain pins possess specialized functionality, as shown in Figure (3.2).

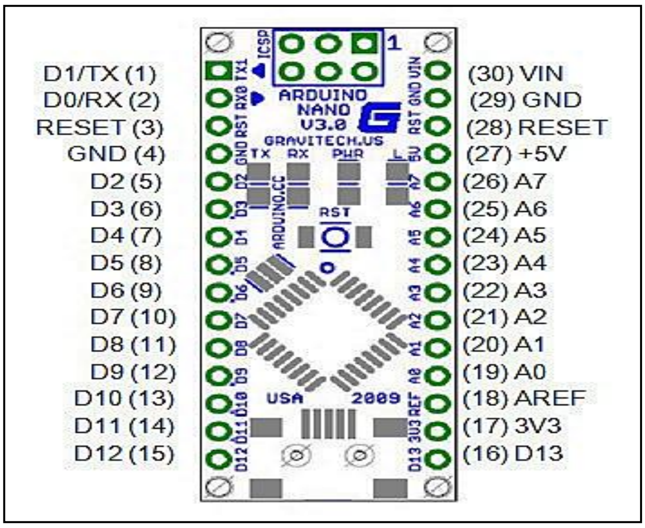


Figure 3.2: The arduino nano pin-Layout [57].

### 3.1.3. Power supply of the Arduino Nano

The Arduino Nano is capable of being powered through the Mini B-USB connection, a 6-20V unregulated external power supply (pin 30), or a 5V regulated external power supply (pin 27). The system automatically selects the power source with the highest voltage.

#### *3.1.3.1. MPU6050 Integrated 6 Axis- motion tracking Device*

The MPU6050 is classified as a motion tracking device that integrates a 3 axis gyroscope and a 3 axis accelerometer, combined with a Digital Motion Processor (DMP) on the same board, The MPU6050 is engineered to execute sophisticated 6-axis Motion Fusion algorithms, catering to the high-performance demands of smartphones, low-power, cost-effective tablets, and wearable sensors. Additionally, the MPU6050 is designed to interface with various non-inertial digital sensors, such as pressure sensors, via its auxiliary I2C port [86].

### *3.1.3.2. The technical specification of MPU6050*

As per the MPU6050 datasheet, it provides digital output of 6-axis Motion Fusion data and 9 axis fused data through the Motion Processing Library. The datasheet enumerates the features encompassed by the MPU6050 as following Figure (3.3):

- The tri-axis angular rate sensor (gyroscope) exhibits a sensitivity of up to 131 LSBs/dps and offers a full-scale range of ±250, ±500, ±1000, and ±2000dps.
- The tri-axis accelerometer features a programmable full-scale range of ±2g, ±4g, ±8g, and ±16g.
- Minimized settling effects and sensor drift by eliminating board-level cross-axis alignment errors between accelerometers and gyroscopes.
- The Digital Motion Processing (DMP) engine delegates intricate motion fusion, sensor timing synchronization, and gesture detection.
- The platform provides support for motion applications on Android, Linux, and Windows operating systems.
- The library includes embedded algorithms for real-time bias and compass calibration, as well as a digital-output temperature sensor [86].
- The FSYNC pin features digital inputs to facilitate video electronic image stabilization and GPS support.

## 3.1.4. Pin-out of mpu-6050

### *3.1.4.1. Configuration of- mpu-6050*

It has in total 8 pins, are listed as following:

- Pin 1, Vcc, supplies power to the module and can range from +3V to +5V, with +5V being the typical voltage used [86].
- Pin 2, connected to the system's Ground, serves as the ground connection.
- Pin 3, denoted as Serial Clock (SCL), is utilized to generate clock pulses for I2C communication.

- Pin 4, designated as Serial Data (SDA), is employed for the transmission of data via I2C communication.
- Pin 5, referred to as Auxiliary Serial Data (XDA), may be utilized to connect other I2C modules to the MPU6050, providing an optional interface.
- Pin 6, designated as Auxiliary Serial Clock (XCL), has the potential to be employed for interfacing other I2C modules with the MPU6050, presenting an optional capability.
- Pin 7, labeled as AD0, enables the adjustment of the address when multiple MPU6050 devices are utilized with a single MCU, offering the flexibility to manage address variation.
- Pin 8, denoted as Interrupt (INT), serves as an interrupt pin designed to signal the availability of data for the MCU to read, as illustrated in (Figure 3.3) below.

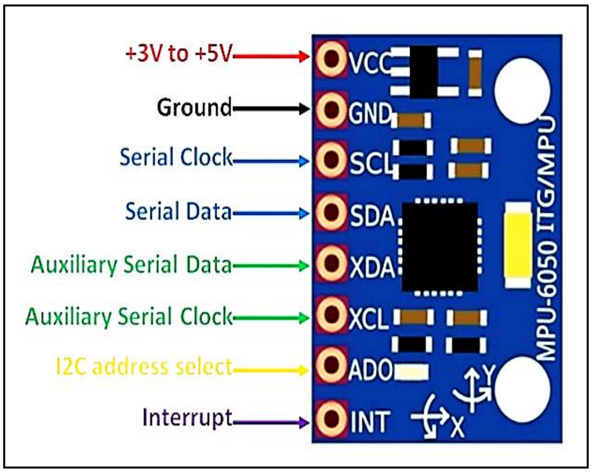


Figure 3.3: Configaration of (mpu- 6050) [57].

### 3.1.5. The software programe of the Arduino-ide

The open source Arduino Software (IDE) provides a user-friendly platform for coding and uploading to the board. Compatible with any Arduino board, this integrated development environment (IDE) includes a text editor for code composition, message area, text console, toolbar featuring common function buttons, and a range of menus. It establishes a connection with Arduino and Genuino hardware in order to upload programs and establish communication [86]. The other microcontroller platforms designed for physical computing applications, such as Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handy board, and others offering similar functionality, the Arduino software (IDE) remains the most extensively used.

***3.1.5.1. Arduino including- sketches***

Code composed using the Arduino Software (IDE) is referred to as sketches. These sketches are authored within the text editor and are saved with the appropriate file extension. The editor encompasses capabilities for text manipulation such as cutting, pasting, searching, and replacing. Moreover, the message area provides feedback during the processes of saving, exporting, and error display [86]. The console exhibits textual output generated by the Arduino Software (IDE), encompassing comprehensive error messages and additional pertinent information. The lower right corner of the interface indicates the configured board and serial port. Additionally, the toolbar provides options for verifying and uploading programs, as well as creating, opening, and saving sketches, along with accessing the serial monitor.

***3.1.5..2 Arduino including- Library***

Libraries offer supplementary functionality for utilization within sketches, such as interfacing with hardware or data manipulation. To incorporate a library into a sketch, it can be selected from the (Sketch > Import Library) menu. This action results in the insertion of one or more #include statements at the beginning of the sketch, and the compilation of the library alongside the sketch. As libraries are uploaded to the board along with the sketch, they contribute to the total space occupied. Should a library become unnecessary for a sketch, its #include statements can be removed from the code's outset [86].

***3.1.5.3. Arduino including- Hardware***

Additional support for third-party hardware can be integrated into the hardware directory within the sketchbook directory. The platforms installed in this location may encompass board definitions, core libraries, bootloaders, and programmer definitions.

***3.1.5.4. Arduino including- Serial text***

This feature showcases the serial data transmitted from the Arduino or Genuino board via USB or a serial connector. In order to transmit data to the board, text input is required along with the use of the send button. It is important to note that on Windows, Mac, or Linux, the board will undergo a reset upon connection to the serial monitor [86] as shown in Figure (2.4) below.

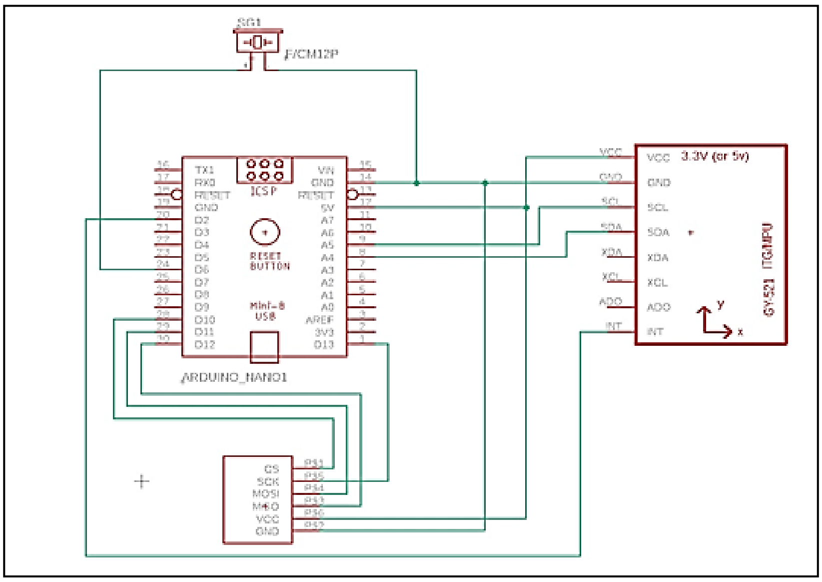


Figure 3.4: Arduino Nano Fused board configuration.

### 3.1.6. Arduino- Nano board

The process of selecting a board has a dual impact: it establishes the parameters (such as CPU speed rate) utilized during the compilation and uploading of sketches, and it configures the file and fuse settings employed by the burn bootloader command as in Figure (3.5).

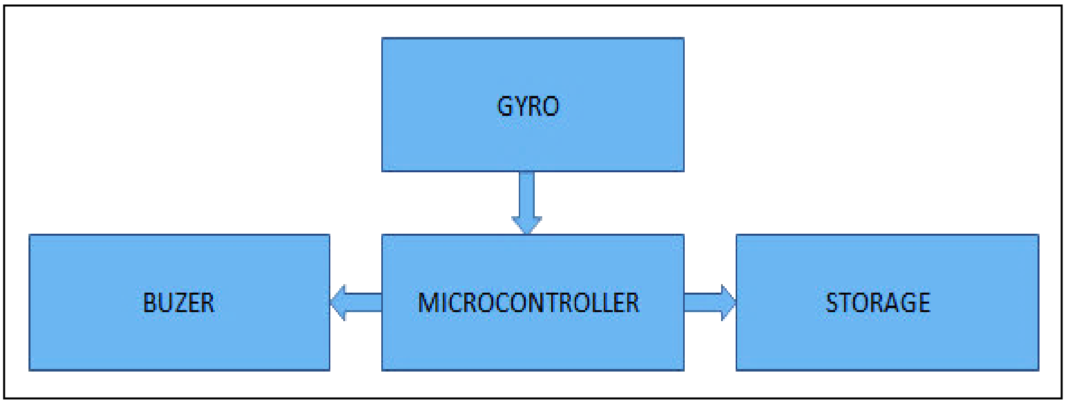


Figure 3.5: Programming procedure of the application by aid of Arduino ide.

## 3.2. MATERIALS

The foundation of our project centers on the creation of a Mechanical Physical model designed to elucidate the tooth brushing process for both adults and children. The primary innovation in our new Modified Multidirectional toothbrush involves the incorporation of various retractable head and handle designs. The implementation process entailed the utilization of software applications such as Fusion 360, 3D Max, and Solid Works. In the evaluation of the usability of the resulting innovative prototypes, common plastic materials such as polyethylene and polypropylene were found to be suitable. The bristles are to be meticulously crafted using specific synthetic materials such as Nylon 6/12, Nylon 11, and Nylon 12, which have been deemed safe and technically appropriate for the intended applications, and are in alignment with the pertinent regulatory stipulations as outlined by the FDA requirements (Figures 3.6- 3.10).

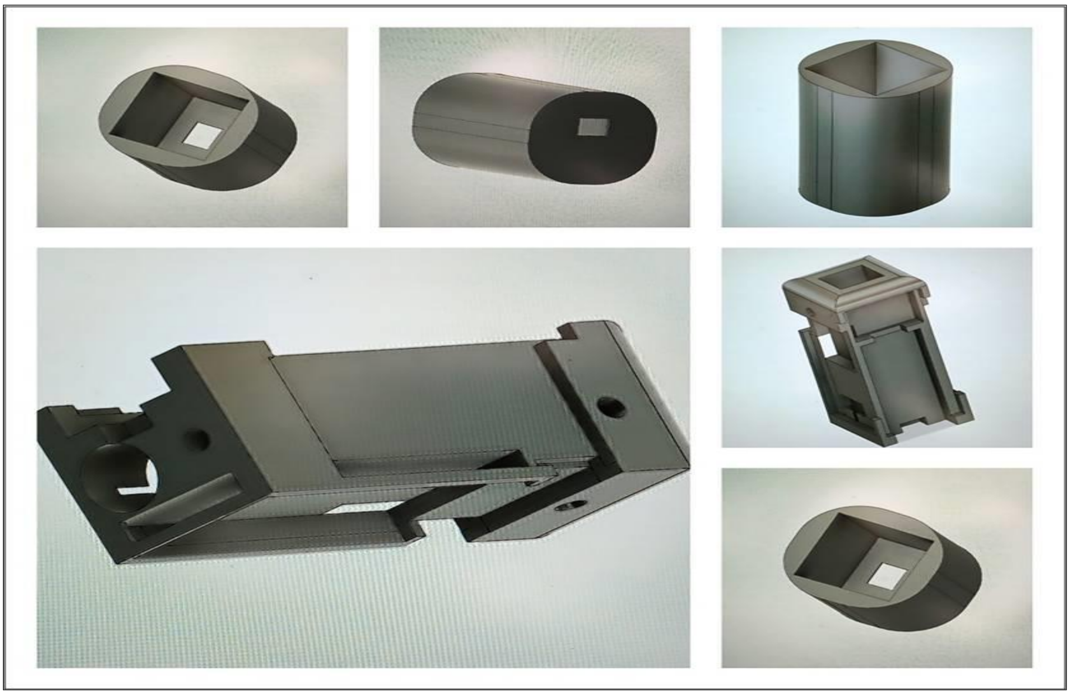

Figure 3.6: Sample of proposed prototype**.**

Figure 3.7: Sample of proposed prototype.

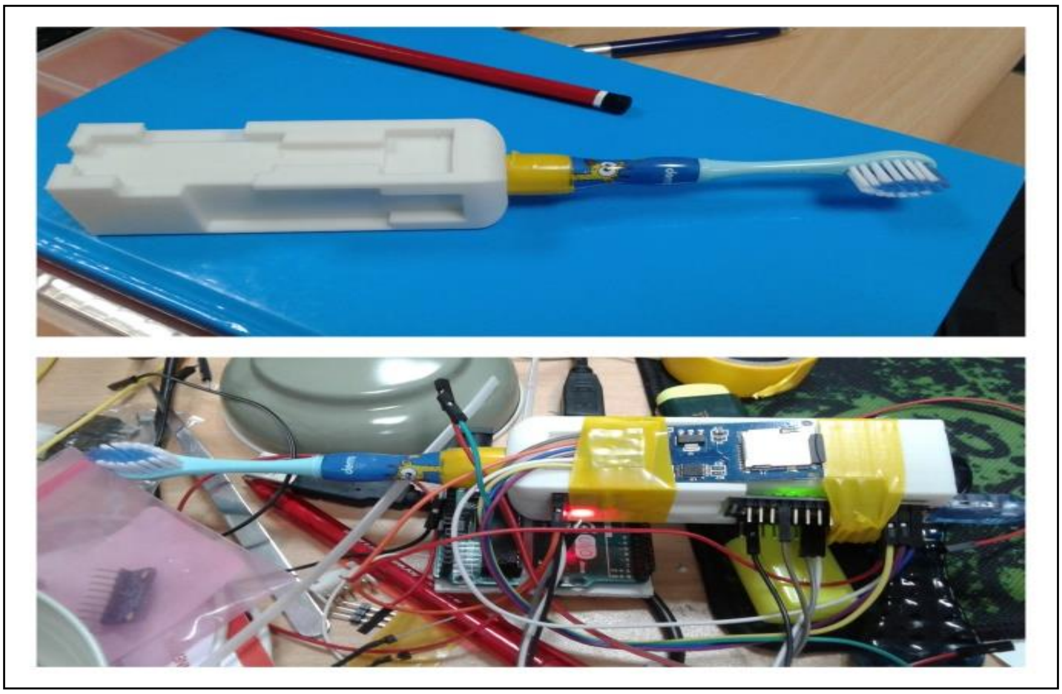

Figure 3.8: Configured proposed prototype.


Figure 3.9: Pre- experimental configuration**.**

Figure 3.10: Pre- experimental configuration.

### 3.3. Experimental Methodology

The second main electronic innovation of our new Modified Multidirectional therapeutic toothbrush comprises the key elements of three types of axis motion application, namely the

Arduino Nano, MPU6050 Integrated 6 Axis, Buzzer, and SD card storage module, Figure (3.11).

Figure 3.11: Configuration of proposed prototype

### 3.3.1. Experiment Setup

#### *3.3.1.1. Subjects*

- 23 subjects, 7 females 16 males, were participated in this study.
- Those subjects are volunteer patients from Hayat Medical Clinics, Istanbul-Turkey.
- All of them have to be asked to sign an acceptance paper individually.
- All of them are using their right hands while brushing.
- They are informed before starting the first phase experiment.
- Participants are trained carefully before starting the second experiment phase, which was scheduled to take place one month after the initial phase (Figure 3.12- 3.13).

### 3.3.2. Data Acquisition and Procedure:

- First USB data cable was connected to the computer after connecting it to the Toothbrush detecting- device.
- Then the toothbrush detecting device is being calibrated at the beginning of each measurement separately.
- Each subject is being called individually to have the experiment in a room of normal conditions (temperature 25 C, free of noises.
- An alarm is applied indicating the standby mode.
- each measurement process last for around 2- 3.5 min.
- The device saves the data that acquired via ARDUINO-NANO and store it as Log and txt files in an SD memory card.

The same experiment procedure is applied for the next subject to end up by data of overall 23 subjects of 10000 in length.

Figure 3.12:.Experimental configuration.

Figure 3.13: Experimental configuration.

### 3.3.3. Data analysis

The data is being processed through MATLAB to generate visual representations of the movement along all three axes, encompassing the X, Y, and Z paths, as shown in Figure (3.13).

The (23) Data from the participants was recorded both before and after the educational phase, with each individual's raw data being segmented into epochs of 10,000 samples in duration, 13 parameters (features) has been computed for each individual epoch and stored for each subject and experiment as **XXX (epc, sbj, exp),** where **XXX** refers to the extracted PARAMETER, AVERAGE over the epoch length was calculated to reduce the results and stored as **AVG_XXX (sbj, exp),** where **AVG_XXX** is the average of specified parameter over the epoch length. The capability of any pattern classification system to discern patterns relies predominantly on the selection of features used to characterize the raw signals. This is exemplified by the variations in patterns observed across different trials table as in Figure (3.12, 3.13, 3.14).

### 3.3.4. Process via Mat lab:

The data is being processed using MATLAB codes to plot all the three axis movement (Figure 3.12, 3.13, 3.14).

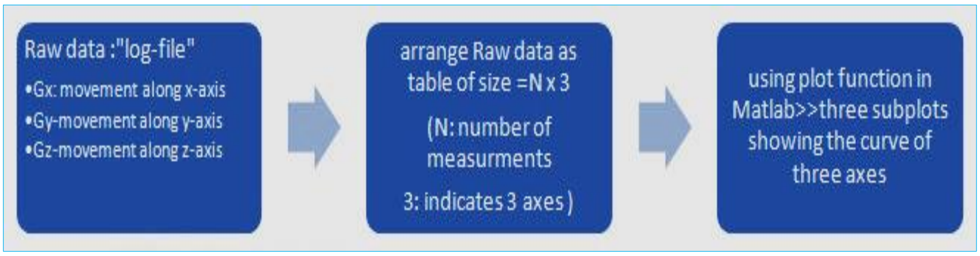


Figure 3.14: Schematic of process via Mat lab.

In this study, different feature parameters were determined in terms of the amplitude and frequency characteristics of the signals. These properties can be easily calculated without any conversion process. Therefore, processing real-time signals is also easy. These features used in this section are explained item by item [106-113]. The used parameters are as shown below.

### 3.3.5. Analysis methods:

1. Each raw subject data was divided into epochs of 500 samples in length
2. 13 parameters (features) has been computed for each individual epoch and stored for each subject and experiment as **XXX (epc, sbj, exp),** where **XXX** refers to the extracted **PARAMETER**.
3. AVERAGE over the epoch length was calculated to reduce the results and stored as **AVG_XXX (sbj, exp),** where **AVG_XXX** is the average of specified parameter over the epoch length.
4. The used parameters are as follows:
    1) Wilson Amplitude (WAMP):
    
       This is the number of times that the difference between two consecutive amplitudes exceeds a certain threshold. It can be formulated as:

$$WAMP = \sum_{i=1}^{N} u(|x_{i+1} - x_i| - T) \tag{3.1}$$

       T = 0.05.
    2) Crossing of Zero- ZC
    
       ZC is the frequency with which the strength of the signal drops to zero.

$$ZC = \sum_{i=1}^{N-1} u(-x_i x_{i+1}) \tag{3.2}$$

3) Amplitude of Mean- MA

The average of the frequency differential between two successive samples is calculated using this function.

$$MAV = \frac{1}{N}\sum_{i=1}^{N}|X_i| \tag{3.3}$$

4) Frequency of Mean- MNF

This function calculates an approximate average frequency of signals for a given interval of time.

$$MF = \frac{\sum_{i=1}^{N} h_i f_i}{\sum_{i=1}^{N} h_i} \tag{3.4}$$

5) Frequency of Median- MDF

Function calculates an approximate average frequency of signal for a given interval of time.

$$MDF = \sum_{j=1}^{MDF} P_j = \sum_{j=MDF}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j \tag{3.5}$$

6) The variance- VAR

Average strength of a randomized signal, variation is defined as follows in the randomized process.

$$VAR = \frac{1}{N-1}\sum_{i=1}^{N} x_i^2 \tag{3.6}$$

7) Coupling of average amplitude- AAC

$$AAC = \frac{1}{N}\sum_{i=1}^{N-1}|X_{i+1} - X_i|$$

(3.7)

8) Standard deviation of difference absolute- DASD

$$DASDV = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N-1}(X_{i+1} - X_i)^2}$$

(3.8)

9) Power wavelet of length- WL

$$WL = \frac{1}{N}\sum_{i=1}^{N-1}|X_{i+1} - X_i|$$

(3.9)

10) Value of log- LOG

$$LOG = e^{\frac{1}{N}\sum_{i=1}^{N} log|x_i|}$$

(3.10)

11) Change of slope sign- SSC

$$SSC = \sum_{i=2}^{N-1}[f(X_i - X_{i-1}) * (X_i - X_{i+1})];$$

$$f(X) = \begin{cases} 1, & Eğer\ X \geq eşik\ değeri \\ 0, & aksi\ takdirde \end{cases}$$

(3.11)

12) Square root mean- RMS

Root of a median square is the measure of the square component of the mean squared in statistics and its applications. The generalised mean with exponential is the quadratic mean, often known as the RMS.

$$RMS = \sqrt{\frac{1}{n}\sum_{i} x_i^2} \tag{3.12}$$

13) The value standard deviation- SD

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}} \tag{3.13}$$

# 4. RESULTS

## 4.1. Results of extracted features (Parameters)

The Tables supplied contain unprocessed data related to the individual participant, organized into 10,000 sample epochs. The number of time segments within the pattern significantly impacts the overall count of feature parameters. Despite substantial temporal structural variation in the signals, it remains plausible that pattern recognition can be attained through statistical stability in waveform.

By analyzing the obtained frequency values, it is evident that the parameters utilized were selected to correspond with the criteria of the proposed model, which functions as a data analyzer for the assessment and detection of the three axes motions (comprising the X, Y, and Z axes) associated with the toothbrush movement trajectories. These trajectories have been configured and refined through statistical analytical procedures as part of our innovative Multidirectional Therapeutic Toothbrush (MTB), As a multiphase optimization application (MOA), which is evident in the tables (4.1- 4.47) provided below, each consisting of 10,000 samples. The raw data for each subject was segmented into epochs, and computations were performed for each individual epoch. These results were then stored for each subject and experiment to demonstrate the variations in patterns across different trials. The subsequent feature parameters, based on temporal and spectral statistics, were then utilized.

The information is undergoing analysis through the MATLAB statistical application to generate plots for all three axes of toothbrush movements. Upon completion of the data processing procedure, the statistical values reveal the recorded data for 23 subjects both before and after the educational phase.

The Table (4.1) displays the sample durations for Experiment 1, which are associated with the teaching mode of the experiment and denoted as the "Before-Teaching the subjects phase" (BTE). The sample durations for Experiment 2, on the other hand, are linked to the teaching mode of the experiment and defined as the "After-Teaching the subjects phase" (ATE).

Table 4.1 :Sample of Subject 01 before training (Signals of Expt.-1).

| x | y | z |
|---|---|---|
| -2.781855828 | 15.45030719 | -19.1827972 |
| -2.960888163 | 16.4563327 | -20.47497883 |
| -3.081263749 | 17.1233905 | -21.3597317 |
| -3.145519144 | 17.45779948 | -21.84469986 |
| -3.160271769 | 17.48848041 | -21.96487293 |
| -3.135444018 | 17.26336813 | -21.77814673 |
| -3.083211005 | 16.84429642 | -21.35903821 |
| -3.016783777 | 16.30089603 | -20.79122158 |
| -2.949154288 | 15.70412767 | -20.15964944 |
| -2.89192926 | 15.12008689 | -19.54303753 |
| -2.85146429 | 14.59727987 | -19.00107894 |
| -2.836460303 | 14.18365381 | -18.58772878 |
| -2.850286006 | 13.90552634 | -18.33236399 |
| -2.893117567 | 13.77235338 | -18.24379322 |
| -2.962241211 | 13.77768343 | -18.31160814 |
| -3.052616514 | 13.90155482 | -18.50929794 |
| -3.157625391 | 14.11399246 | -18.79868684 |
| -3.269917224 | 14.37917177 | -19.13514641 |
| -3.382256366 | 14.65977981 | -19.4729908 |

The primary objective derived from experiments 1 and 2 is to monitor, stabilize, and standardize the movements of the toothbrush in the balanced position, encompassing the three axes pathways of X, Y, and Z. These orientations have been established and refined through statistical analytical procedures as part of our innovative Multidirectional Therapeutic Toothbrush (MTB). This approach serves as a multiphase optimization application (MOA).

The Table (4.2) presents a selection of 10,000 samples in length. The raw data for each subject was segmented into epochs, and computations were performed for each individual epoch. These results were then stored for each subject's experiment to demonstrate the variations in patterns across different trials. The subsequent feature parameters, based on temporal and spectral statistics, were utilized to generate the comprehensive feature set necessary to depict the behavior of each pattern.

Table 4.2: Sample of Subject 01 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| 12.48839585 | 10.01673417 | -20.76395945 |
| 12.96409121 | 10.37782511 | -21.55921444 |
| 13.35187887 | 10.6657264 | -22.21065082 |
| 13.65055174 | 10.87971032 | -22.71662381 |
| 13.8609287 | 11.02072805 | -23.07881853 |
| 13.98578323 | 11.0913443 | -23.30211567 |
| 14.02971818 | 11.09562741 | -23.39436864 |
| 13.99899131 | 11.03899881 | -23.36610004 |
| 13.90129766 | 10.92804712 | -23.23012862 |
| 13.74551618 | 10.77031302 | -23.00113912 |
| 13.54142884 | 10.57405218 | -22.69520966 |
| 13.29942161 | 10.34798383 | -22.32931215 |
| 13.03017652 | 10.10103299 | -21.92080184 |
| 12.74436474 | 9.842074492 | -21.48691227 |
| 12.45234999 | 9.579686666 | -21.04427121 |
| 12.16391114 | 9.32192204 | -20.60845237 |
| 11.88799221 | 9.076101793 | -20.19357598 |
| 11.62886651 | 8.846340238 | -19.80859963 |
| 11.39637307 | 8.64001646 | -19.46674031 |

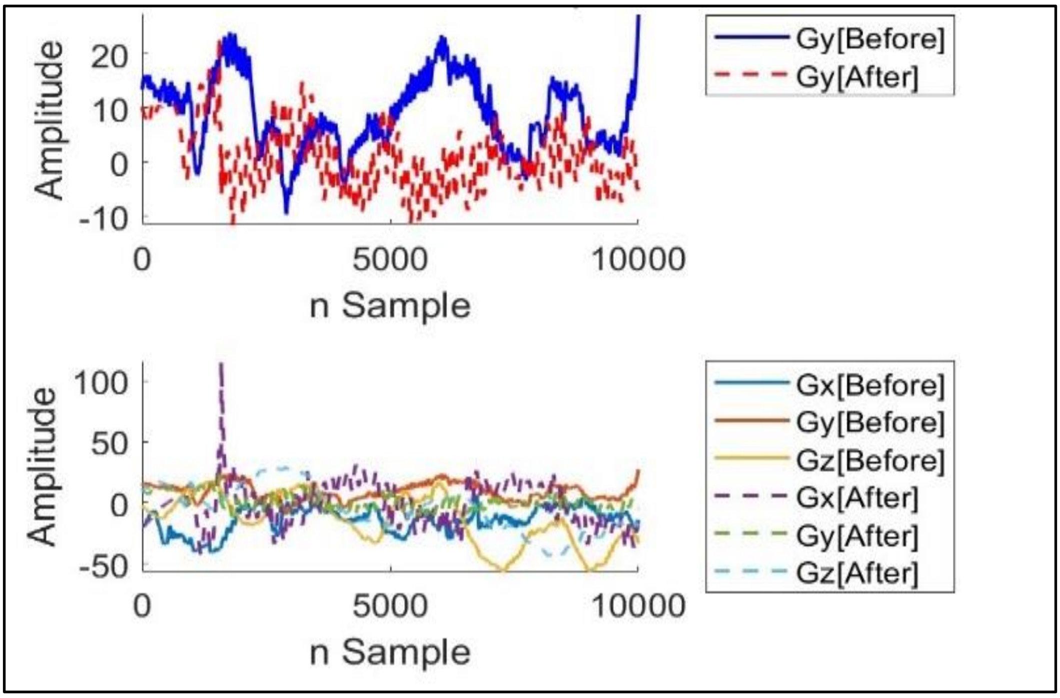


Figure 4.1: Subject 1 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Referring to Figure (4.1) shown above, it is observed that the majority of parameter values demonstrate a decrease from the before to the after experiments. For instance, the mean absolute value (MAV) measures the average disparity between signal amplitudes or the rate of fluctuation (utilizing the suggested electronic equipment). Through comparing the three axes X, Y, and Z of the movement signals, we are able to identify the specific locations where the toothbrush displays consistent motion signals, as evident from the data.

When comparing the amplitudes displayed above, the upper portion represents Gy, while the lower portion represents Gx, Gy, and Gz amplitudes after the experiment. The amplitude range of the after-experiment phase illustrates the benefit of our model. The average reduction in movement amplitude between the two experiments is approximately 75%, indicating the potential for monitoring and determining the related behavioral tooth brushing skills in order to minimize errors.

The subject's recorded data is undergoing processing in MATLAB to evaluate the movement along all three axes. Upon completion of the data processing, the statistical values reveal information pertaining to the 23 subject datasets recorded before and after the educational phase.

The Table (4.3) shown below demonstrates the segmentation of the raw subject data into epochs, with computations performed for each individual epoch and subsequently stored for each subject and experiment. This process aims to depict the variations in patterns across different trials and generate the comprehensive feature set necessary to represent the tooth brushing behavior of each pattern.

Table 4.3: Sample of Subject 02 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 41.80768365 | -27.41815539 | -30.00987153 |
| 45.21472762 | -29.63517688 | -32.38963571 |
| 47.14510626 | -30.87785051 | -33.68616211 |
| 47.69440588 | -31.20914911 | -33.96918863 |
| 47.10746715 | -30.79025204 | -33.41713293 |
| 45.7336087 | -29.85113181 | -32.28478924 |
| 43.96930183 | -28.65289121 | -30.86189409 |
| 42.19794207 | -27.44817526 | -29.42948722 |
| 40.70996612 | -26.43130304 | -28.20829692 |
| 39.74009714 | -25.75501525 | -27.36698527 |
| 39.38429671 | -25.48228923 | -26.9771357 |
| 39.6192826 | -25.59735636 | -27.02277451 |
| 40.32263577 | -26.01899431 | -27.41485214 |
| 41.30649796 | -26.62281639 | -28.01576726 |
| 42.35804808 | -27.26805599 | -28.66898364 |
| 43.25284336 | -27.80945536 | -29.21630274 |
| 43.8636203 | -28.16051859 | -29.55658028 |
| 44.11625304 | -28.27180892 | -29.6317951 |
| 44.01284901 | -28.14429202 | -29.4396341 |

The Table (4.4) presented below displays the sample lengths of Experiment 1, characterized by the teaching mode of the experiment and denoted as the "Before-Teaching the subjects" phase (BTE). Similarly, the sample lengths of Experiment 2 are determined based on the experiment's teaching mode and defined as the "After-Teaching the subjects" phase (ATE). The data underwent processing using the MATLAB statistical application to visualize the movements along all three axes (utilizing the suggested electronic equipment). Upon completion of the data processing, the statistical values provide insight into the 23 subject datasets recorded before and after the educational phase.

Table 4.4: : Sample of Subject 02 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.301394199 | 0.780472815 | 28.99756691 |
| -2.613336625 | 0.892882595 | 32.81480087 |
| -2.546079227 | 0.875836873 | 31.82536557 |
| -2.321406323 | 0.800484939 | 28.88750023 |
| -2.172081428 | 0.744804639 | 26.99522468 |
| -2.192880534 | 0.744497312 | 27.35521937 |
| -2.311400261 | 0.780472815 | 29.01757903 |
| -2.391422134 | 0.809696234 | 30.20470028 |
| -2.370901596 | 0.809961732 | 30.07606844 |
| -2.291388137 | 0.790478877 | 29.13765177 |
| -2.23223549 | 0.77296058 | 28.42133288 |
| -2.239839523 | 0.771369548 | 28.55380594 |
| -2.291388137 | 0.780472815 | 29.26773058 |
| -2.329000334 | 0.785411381 | 29.8107615 |
| -2.328766629 | 0.782559356 | 29.80947435 |
| -2.311400261 | 0.780472815 | 29.44783969 |
| -2.309754981 | 0.788355569 | 29.10731975 |
| -2.343941804 | 0.810377274 | 29.05992614 |
| -2.401454817 | 0.840509186 | 29.21770027 |

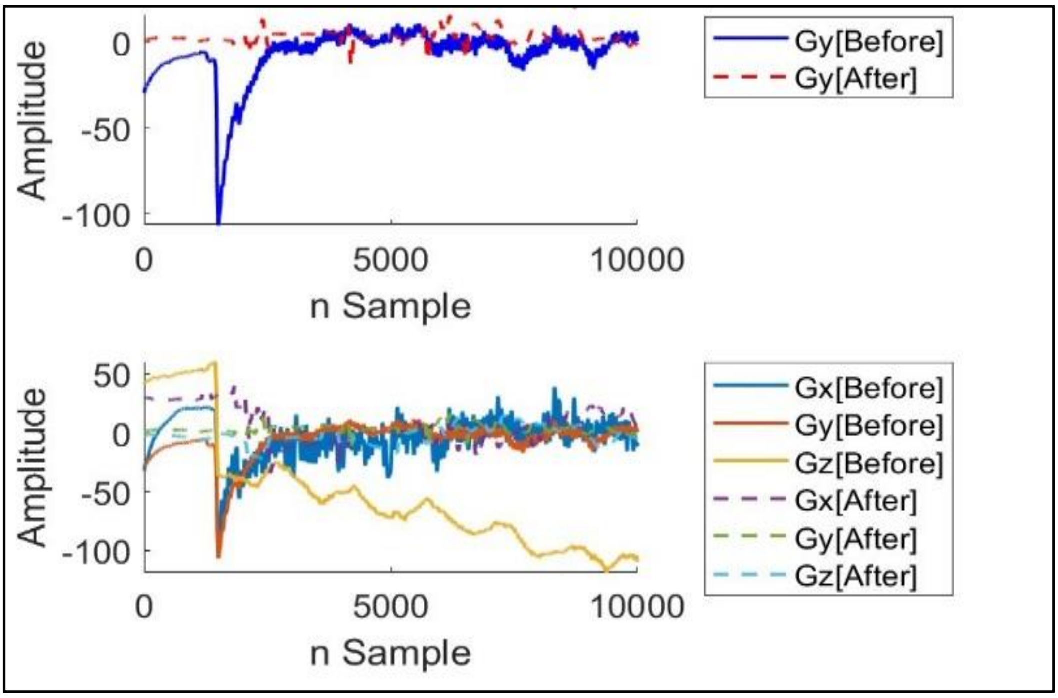


Figure 4.2: Subject 2 Mean and median frequency spectrum of BEFORE and AFTER experiments.

As illustrated in Figure (4.2), through a comparison of the movement signals along the three axes X, Y, and Z, specific locations where the toothbrush displays consistent motion signals can be accurately identified. The upper section represents Gy, while the lower section represents Gx, Gy, and Gz. The amplitude range of the after-experiment phase highlights the advantageous aspects of our model.

Furthermore, the decrease in Mean and Median components, based on frequency (utilizing the suggested electronic equipment), indicates the stability in toothbrush usage following the application of the learning model.

The Table 4.5 presents the sample lengths of Experiment 1, identified according to the experiment's teaching mode and designated as the "Before-Teaching the subjects" phase (BTE). Similarly, the sample lengths of Experiment 2 are determined based on the experiment's teaching mode and defined as the "After-Teaching the subjects" phase (ATE).

Table 4.5: Sample of Subject 03 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 21.78456424 | 10.06673019 | -3.95264257 |
| 23.09103935 | 10.66148316 | -4.215676166 |
| 24.01658445 | 11.07839438 | -4.416398752 |
| 24.56536952 | 11.31961461 | -4.55547367 |
| 24.76281735 | 11.39716393 | -4.637200757 |
| 24.65286735 | 11.33164092 | -4.669033641 |
| 24.29399605 | 11.15035636 | -4.660880314 |
| 23.75434188 | 10.88505465 | -4.624248961 |
| 23.10634533 | 10.56941556 | -4.571312493 |
| 22.42134387 | 10.23654144 | -4.513970294 |
| 21.76455086 | 9.916629839 | -4.462983762 |
| 21.18186918 | 9.631484004 | -4.423502002 |
| 20.72215477 | 9.403094585 | -4.405221955 |
| 20.41235132 | 9.243715451 | -4.412448448 |
| 20.26367032 | 9.158289303 | -4.44686467 |
| 20.27223391 | 9.144781342 | -4.507652926 |
| 20.42086459 | 9.195046264 | -4.591804249 |
| 20.68180176 | 9.296122954 | -4.694578723 |
| 21.02006087 | 9.431820976 | -4.810068128 |

It is emphasized that the primary objective is to monitor, stabilize, and standardize the movements of the toothbrush in the equilibrium position, encompassing the paths along the three axes (X, Y, Z). These directives have been established and tailored using statistical analytical methods through our proposed (MTB) as a multiphase optimization application (MOA)

In The Table (4.6) shown below presents the raw subject data was segmented into epochs, with computations performed for each individual epoch and subsequently stored for each subject and experiment to demonstrate the variances in patterns across different trials. The feature parameters based on temporal and spectral statistics are utilized to produce the comprehensive feature set necessary to represent the behavior of each pattern.

Table 4.6: Sample of Subject 03 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| 21.78458744 | 10.06674091 | -3.952646779 |
| 22.9879215 | 10.6147256 | -4.19432322 |
| 23.8767692 | 11.01587194 | -4.384563682 |
| 24.4520041 | 11.27074576 | -4.523479454 |
| 24.72928009 | 11.38677907 | -4.613712372 |
| 24.73752705 | 11.37755882 | -4.660169076 |
| 24.51669725 | 11.26176849 | -4.669624526 |
| 24.11492792 | 11.0618602 | -4.650224156 |
| 23.58532027 | 10.80255142 | -4.610920524 |
| 22.98255687 | 10.50925 | -4.560884051 |
| 22.35958392 | 10.20651309 | -4.508928342 |
| 21.76457403 | 9.916640399 | -4.462988515 |
| 21.23030894 | 9.655312557 | -4.426305035 |
| 20.795191 | 9.439758522 | -4.406744267 |
| 20.48107354 | 9.27993447 | -4.407809398 |
| 20.29905119 | 9.180792548 | -4.431209024 |
| 20.24968621 | 9.1424074 | -4.476903502 |
| 20.32390999 | 9.160417284 | -4.543262859 |
| 20.50449972 | 9.226731478 | -4.627318675 |

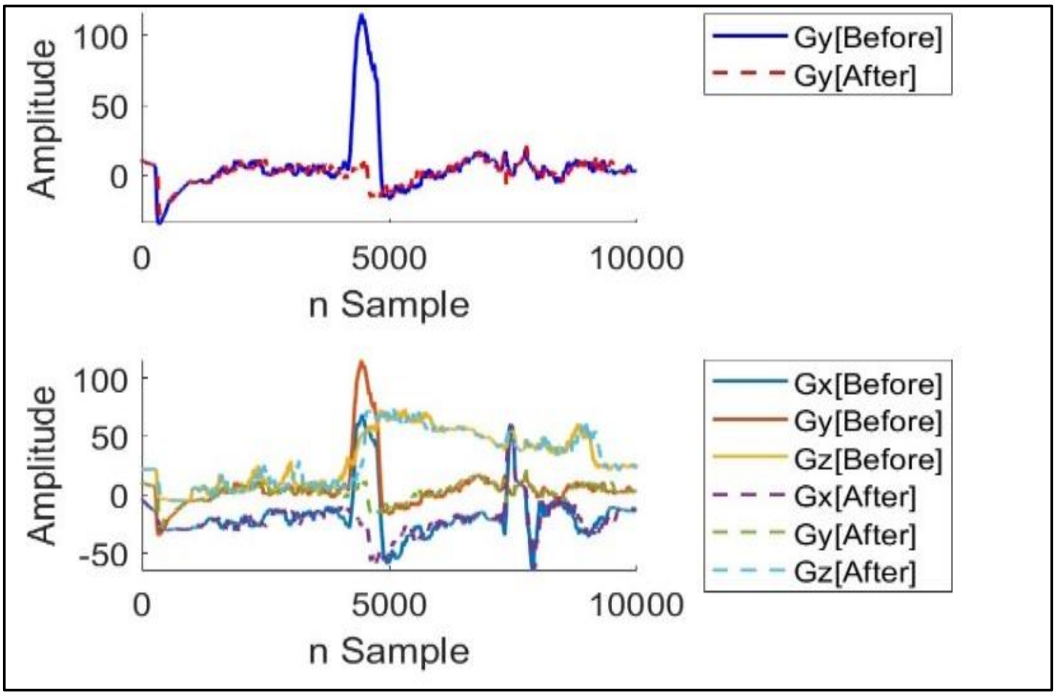


Figure 4.3: Subject 3 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Based on the suggested electronic equipment, the decrease in Mean and Median components based on frequency indicates the stability in toothbrush usage following the application of the learning model. Additionally, as most parameter values demonstrate a decrease from the pre-experiment phase to the post-experiment phase, the Mean Absolute Value (MAV) measures the average difference between signal amplitudes or the rate of fluctuation. Through a comparison of the movement signals along the three axes X, Y, and Z, specific locations where the toothbrush displays consistent motion signals can be accurately identified.

The Figure (4.3) shown above depicts the representation of Gy at the top, and Gx, Gy, Gz at the bottom. The amplitude ranges observed after the experiment distinctly illustrate the benefits of our model.

According to the data is being processing in MATLAB for the visualization of the three axes movements (Table 4.7), subsequent to the completion of the data processing procedure, the statistical findings demonstrate that the data of 23 subjects have been documented both before and after the educational phase.

The Table 4.7 displays the sample durations of Experiment 1, determined according to the teaching mode of the experiment, denoted as the Before Teaching the Subjects Phase (BTE). Likewise, the sample durations of Experiment 2 are determined based on the experiment's teaching mode, referred to as the After Teaching the Subjects Phase (ATE).

Table 4.7: Sample of Subject 04 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 40.39656607 | 19.08254929 | -46.15034994 |
| 43.9766244 | 20.81362084 | -50.2493688 |
| 45.58962299 | 21.62328055 | -52.10038474 |
| 45.45302913 | 21.60808069 | -51.94802194 |
| 44.02967627 | 20.97987067 | -50.31674165 |
| 41.92014796 | 20.0163446 | -47.88869129 |
| 39.73613174 | 19.00249665 | -45.35983007 |
| 37.95562057 | 18.16372902 | -43.28064581 |
| 36.91747546 | 17.66172506 | -42.03412275 |
| 36.72140806 | 17.54827145 | -41.73441007 |
| 37.25919329 | 17.77863333 | -42.25888383 |
| 38.27079802 | 18.23674549 | -43.31218341 |
| 39.42592774 | 18.77234529 | -44.51927729 |
| 40.38336819 | 19.22821589 | -45.49877229 |
| 40.93944244 | 19.5085583 | -46.01592288 |
| 41.00565217 | 19.56920781 | -45.97023359 |
| 40.62884547 | 19.42744281 | -45.41511115 |
| 39.96081132 | 19.14858677 | -44.52354908 |
| 39.20578297 | 18.82237819 | -43.52862581 |

The primary purpose of our newly designed electronic device is to monitor, stabilize, and standardize the movement of the toothbrush to maintain its equilibrium position across the X, Y, and Z axes pathways. These orientations have been established and allocated through statistical analytical methods as part of our innovative Multidirectional Therapeutic Toothbrush (MTB), serving as a multiphase optimization application (MOA).

The Table (4.8) illustrates the variations in patterns across different trials, utilizing feature parameters derived from temporal and spectral statistics to construct the comprehensive feature set necessary for representing the behavior of each pattern.

Table 4.8: Sample of Subject 04 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| 40.39656607 | 19.08254929 | -46.15034994 |
| 43.9766244 | 20.81362084 | -50.2493688 |
| 45.58962299 | 21.62328055 | -52.10038474 |
| 45.45302913 | 21.60808069 | -51.94802194 |
| 44.02967627 | 20.97987067 | -50.31674165 |
| 41.92014796 | 20.0163446 | -47.88869129 |
| 39.73613174 | 19.00249665 | -45.35983007 |
| 37.95562057 | 18.16372902 | -43.28064581 |
| 36.91747546 | 17.66172506 | -42.03412275 |
| 36.72140806 | 17.54827145 | -41.73441007 |
| 37.25919329 | 17.77863333 | -42.25888383 |
| 38.27079802 | 18.23674549 | -43.31218341 |
| 39.42592774 | 18.77234529 | -44.51927729 |
| 40.38336819 | 19.22821589 | -45.49877229 |
| 40.93944244 | 19.5085583 | -46.01592288 |
| 41.00565217 | 19.56920781 | -45.97023359 |
| 40.62884547 | 19.42744281 | -45.41511115 |
| 39.96081132 | 19.14858677 | -44.52354908 |
| 39.20578297 | 18.82237819 | -43.52862581 |

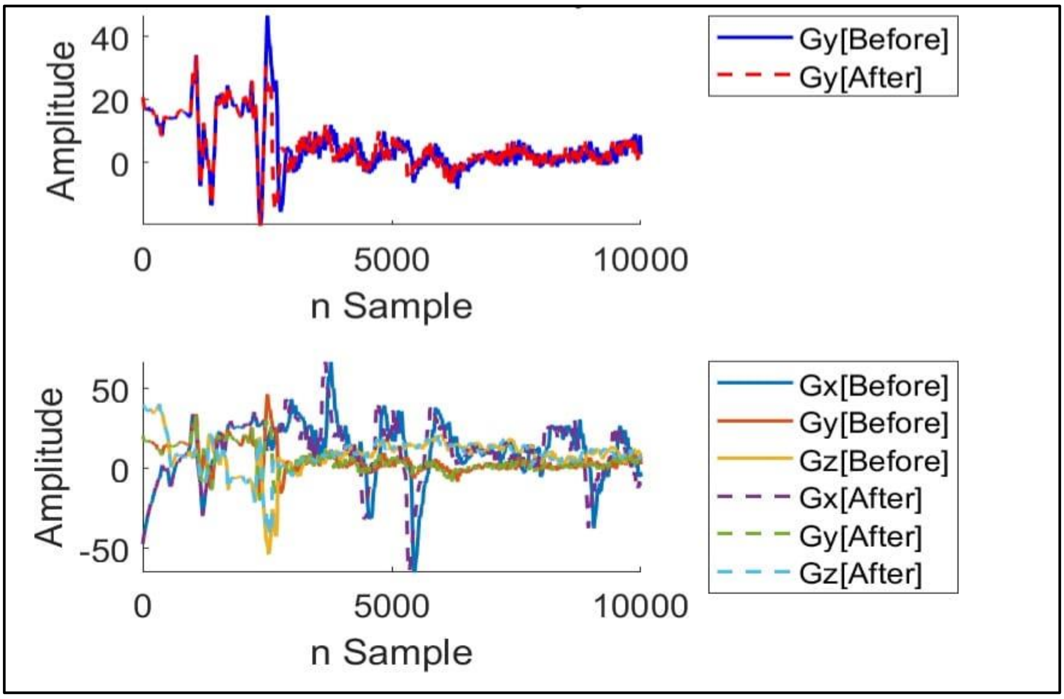


Figure 4.4: Subject 4 Mean and median frequency spectrum of BEFORE and AFTER experiments.

By considering the frequency of Mean and Median components depicted in the aforementioned figure (4.4), the observed decrease signifies the stability achieved when utilizing the toothbrush with our proposed electronic device following the implementation of the learning model. Through the comparison of the movement signals along the X, Y, and Z axes, distinct locations where the toothbrush demonstrates consistent motion signals can be clearly identified.

The illustration in Figure (4.4) shown above depicts the representation of Gy at the top and Gx, Gy, Gz at the bottom. The amplitude range observed in the post-experiment phase highlights the effectiveness of our model, indicating an average reduction of 75% in movement amplitude between the two experiments.

The Table (4.9) presented below illustrates the samples from Experiment 1, identified according to the experiment's teaching mode and denoted as the Before Teaching the Subjects Phase (BTE). Additionally, the sample durations from Experiment 2, determined based on the experiment's teaching mode using the proposed electronic equipment, are defined as the After Teaching the Subjects Phase (ATE).

Table 4.9: Sample of Subject 05 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -507.738722 | -30.41028727 | -7.164779758 |
| -541.1667213 | -32.34828524 | -7.46369071 |
| -563.642159 | -33.61449367 | -7.563035228 |
| -575.4026596 | -34.22469999 | -7.46902358 |
| -577.4209714 | -34.23939503 | -7.199972294 |
| -571.2840397 | -33.75634857 | -6.784233044 |
| -559.0224321 | -32.90018007 | -6.2573531 |
| -542.9081777 | -31.81002625 | -5.65876004 |
| -525.2417096 | -30.62656362 | -5.028297352 |
| -508.1489957 | -29.47966644 | -4.402937282 |
| -493.1723798 | -28.46750964 | -3.824850164 |
| -481.8135785 | -27.67827297 | -3.308290182 |
| -474.8631365 | -27.15945811 | -2.865918318 |
| -472.5569122 | -26.92454179 | -2.500591393 |
| -474.6127022 | -26.95531977 | -2.206200078 |
| -480.314092 | -27.20714631 | -1.969349729 |
| -488.6297371 | -27.61633657 | -1.771653145 |
| -498.3534186 | -28.10882284 | -1.592349357 |
| -508.2490624 | -28.60908566 | -1.410941265 |

It is emphasized that the primary objective is to monitor, stabilize, and standardize the movements of the toothbrush in its equilibrium position across the X, Y, and Z axes. So the Table 4.10 displays signal samples of varying lengths. Each raw dataset from the subjects was segmented into epochs, with computations performed for each individual epoch and stored for each subject and experiment.

This approach is utilized to demonstrate the differences in patterns across different trials, employing feature parameters based on temporal and spectral statistics using the proposed electronic equipment to generate the comprehensive feature set needed to represent the behavior of each pattern.

Table 4.10: Sample of Subject 05 after training (Sign. of Expt.-2).

| x | Y | z |
|---|---|---|
| -507.7394531 | -30.41033106 | -7.164790075 |
| -538.314687 | -32.18460914 | -7.442780778 |
| -560.0238298 | -33.41496417 | -7.559028769 |
| -572.955706 | -34.10776902 | -7.516666514 |
| -577.6939396 | -34.29949565 | -7.326988251 |
| -575.2539625 | -34.05284089 | -7.008358391 |
| -566.9910609 | -33.45109804 | -6.584669095 |
| -554.4874774 | -32.59126362 | -6.083478438 |
| -539.428085 | -31.57645882 | -5.533980986 |
| -523.4748044 | -30.50828374 | -4.964969892 |
| -508.1497274 | -29.47970889 | -4.402943622 |
| -494.5258009 | -28.55981408 | -3.880190528 |
| -483.7506228 | -27.8155528 | -3.405933911 |
| -476.4614927 | -27.28529949 | -2.990489878 |
| -472.9300144 | -26.98498384 | -2.637686857 |
| -473.0760942 | -26.90900664 | -2.345223114 |
| -476.5086178 | -27.03279279 | -2.105503234 |
| -482.587785 | -27.31666903 | -1.906855042 |
| -490.5025649 | -27.7106613 | -1.734999326 |

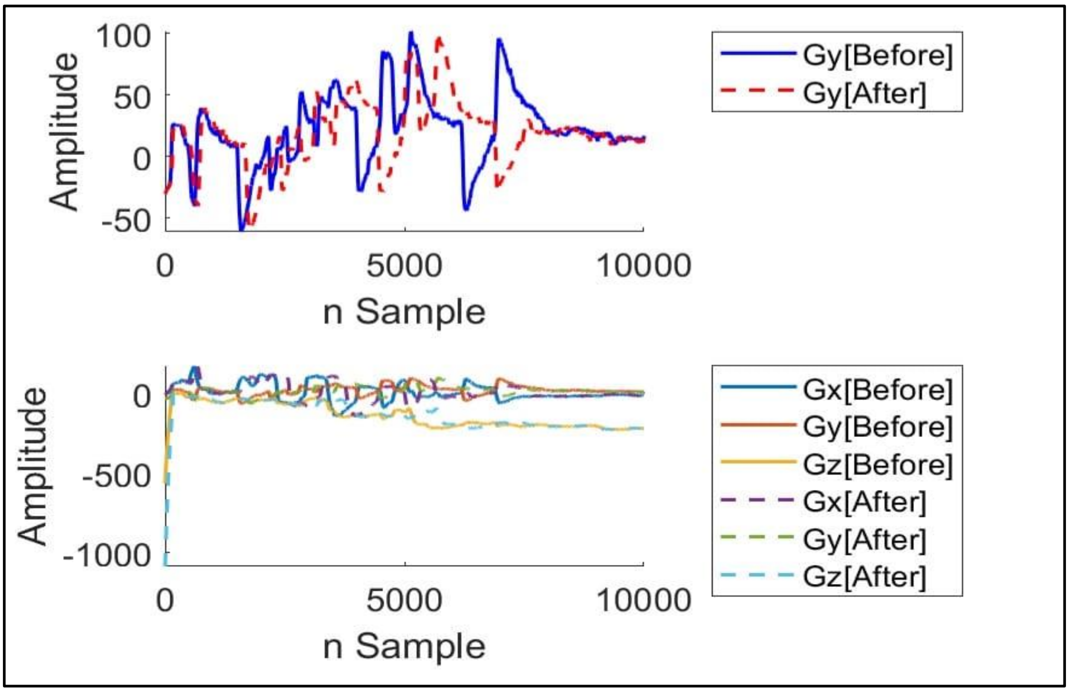


Figure 4.5: Subject 5 Mean and median frequency spectrum of BEFORE and AFTER experiments.

The decline in the frequency of the Mean and Median components suggests the enhanced stability in utilizing the toothbrush with our proposed electronic equipment following the implementation of the learning model.

As depicted in Figure (4.5) shown above, the majority of parameter values demonstrate a reduction between the before and after experiments, with the MAV assessing the average variance in signal amplitudes or fluctuation rate (using the proposed electronic equipment). Through a comparison of the movement signals along the X, Y, and Z axes, specific locations where the toothbrush displays consistent motion signals can be distinctly identified.

The sample durations presented in Table 4.11 illustrate the lengths of samples from Experiment 1, obtained using the proposed electronic equipment, and identified according to the experiment's teaching mode as the Before-Teaching the Subjects Phase (BTE). Similarly, the sample durations from Experiment 2, also detected based on the experiment's teaching mode, are defined as the After-Teaching the Subjects Phase (ATE).

That the data is being processed using MATLAB to assess the three axes movement.

Table 4.11: Sample of Subject 06 before training (Sign. of Expt.-1).

| x | Y | z |
|---|---|---|
| 105.1396199 | 4.282835951 | 15.26010473 |
| 113.5169656 | 4.763519242 | 16.45447517 |
| 118.1291784 | 5.12478321 | 17.09947723 |
| 119.2296028 | 5.3660281 | 17.23420538 |
| 117.451158 | 5.499797936 | 16.95272377 |
| 113.6916705 | 5.549055164 | 16.38700946 |
| 108.9673555 | 5.543221926 | 15.68536474 |
| 104.2590368 | 5.513650955 | 14.98992583 |
| 100.3104751 | 5.487280061 | 14.41155333 |
| 97.71731493 | 5.488640607 | 14.03103274 |
| 96.72055563 | 5.532735121 | 13.87956133 |
| 97.25517919 | 5.625411751 | 13.9436332 |
| 99.00186043 | 5.763835492 | 14.17331475 |
| 101.4734662 | 5.938166245 | 14.49555048 |
| 104.1189441 | 6.134061771 | 14.82981981 |
| 106.3602275 | 6.334036149 | 15.09786269 |
| 107.8642286 | 6.524501629 | 15.25129279 |
| 108.4364297 | 6.694327317 | 15.26562913 |
| 108.0789086 | 6.837195489 | 15.14530077 |

The primary function of our proposed electronic equipment is to observe, stabilize, and standardize the motion of the toothbrush in its equilibrium position, encompassing the three axes pathways of X, Y, and Z.

The Table 4.12 displays a selection of signals from each subject, demonstrating the variations in patterns across different trials. The feature parameters, derived from temporal and spectral statistics, are utilized to generate the comprehensive feature set necessary to characterize the behavior of each pattern.

Table 4.12: Sample of Subject 06 after training (Signals of Expt.-2).

| x | y | z |
|---|---|---|
| 105.1396199 | 4.282835951 | 15.26010473 |
| 113.5169656 | 4.763519242 | 16.45447517 |
| 118.1291784 | 5.12478321 | 17.09947723 |
| 119.2296028 | 5.3660281 | 17.23420538 |
| 117.451158 | 5.499797936 | 16.95272377 |
| 113.6916705 | 5.549055164 | 16.38700946 |
| 108.9673555 | 5.543221926 | 15.68536474 |
| 104.2590368 | 5.513650955 | 14.98992583 |
| 100.3104751 | 5.487280061 | 14.41155333 |
| 97.71731493 | 5.488640607 | 14.03103274 |
| 96.72055563 | 5.532735121 | 13.87956133 |
| 97.25517919 | 5.625411751 | 13.9436332 |
| 99.00186043 | 5.763835492 | 14.17331475 |
| 101.4734662 | 5.938166245 | 14.49555048 |
| 104.1189441 | 6.134061771 | 14.82981981 |
| 106.3602275 | 6.334036149 | 15.09786269 |
| 107.8642286 | 6.524501629 | 15.25129279 |
| 108.4364297 | 6.694327317 | 15.26562913 |
| 108.0789086 | 6.837195489 | 15.14530077 |

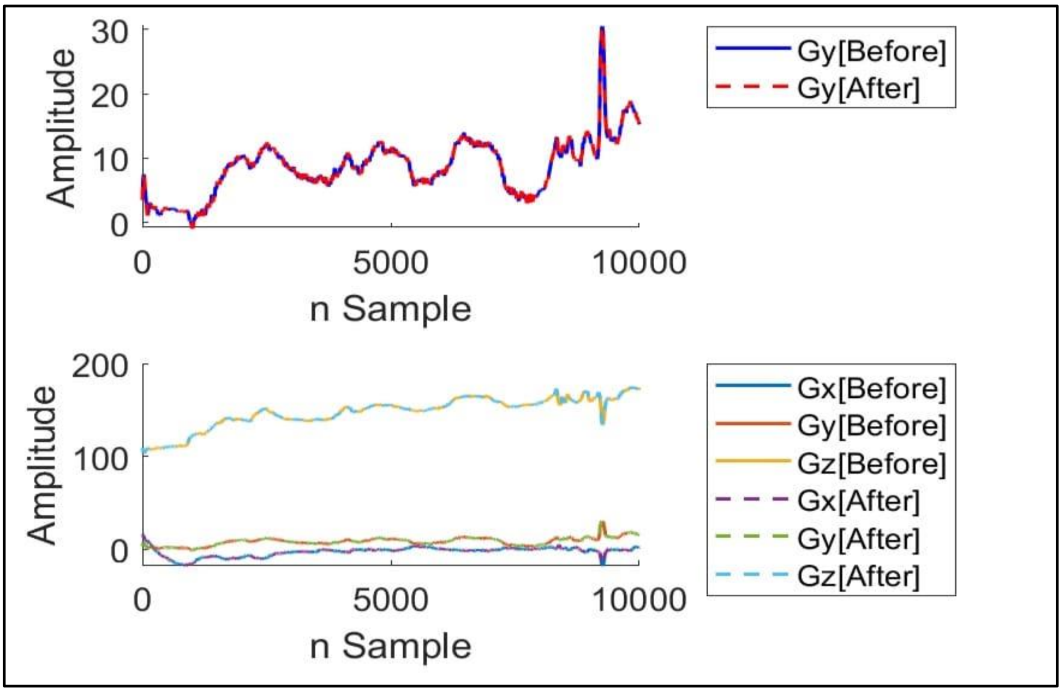


Figure 4.6: Subject 6 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Through the comparison of the X, Y, and Z axes of the toothbrush movements, we can identify specific locations where our proposed electronic equipment demonstrates consistent motion signals, as evident from the analysis.

The depicted Figure (4.6) shown above illustrates the amplitude ranges of the AFTER phase experiment, with the top representing Gy and the bottom representing Gx, Gy, and Gz. This presentation highlights the benefit of our model, as the decrease in frequency mean and median components indicates the stability achieved when using the toothbrush after implementing the learning mode.

The Table 4.13 presents the signal lengths of Experiment 1, identified according to the experiment's teaching mode as the Before-Teaching the Subjects Phase (BTE). Likewise, the signal lengths of Experiment 2 are detected based on the experiment's teaching mode and defined as the After-Teaching the Subjects Phase (ATE).

The data is undergoing processing through the MATLAB statistical application to evaluate the movement across all three axes.

Table 4.13: Sample of Subject 07 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -1.060702362 | 15.43021737 | 101.8074135 |
| -1.157247967 | 16.66842211 | 109.8691021 |
| -1.218341214 | 17.35494348 | 114.2602008 |
| -1.244922526 | 17.52550073 | 115.2216431 |
| -1.241269746 | 17.27138287 | 113.3623478 |
| -1.214073638 | 16.7228713 | 109.5486931 |
| -1.171257273 | 16.02799107 | 104.7632098 |
| -1.120742118 | 15.33015111 | 99.95618765 |
| -1.071669329 | 14.74053343 | 95.86687966 |
| -1.026985261 | 14.34579969 | 93.06335572 |
| -0.988689834 | 14.18220758 | 91.78158915 |
| -0.9564184 | 14.24134273 | 91.96173406 |
| -0.928021467 | 14.47754571 | 93.29849458 |
| -0.900424894 | 14.82044438 | 95.32519912 |
| -0.870576467 | 15.19005835 | 97.51457089 |
| -0.839132792 | 15.5043602 | 99.33185075 |
| -0.802828699 | 15.71267481 | 100.4474387 |
| -0.761610352 | 15.78554035 | 100.6756365 |
| -0.716620762 | 15.72184455 | 100.0186273 |

The Table 4.14 displays a subset of 10,000 signal length samples. Each raw subject data has been segmented into epochs, with computations performed for each individual epoch and stored for each subject and experiment. This approach serves to showcase the variations in patterns across different trials, with the utilization of feature parameters based on temporal and spectral statistics.

Table 4.14: Sample of Subject 07 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.301394199 | 0.780472815 | 28.99756691 |
| -2.613336625 | 0.892882595 | 32.81480087 |
| -2.546079227 | 0.875836873 | 31.82536557 |
| -2.321406323 | 0.800484939 | 28.88750023 |
| -2.172081428 | 0.744804639 | 26.99522468 |
| -2.192880534 | 0.744497312 | 27.35521937 |
| -2.311400261 | 0.780472815 | 29.01757903 |
| -2.391422134 | 0.809696234 | 30.20470028 |
| -2.370901596 | 0.809961732 | 30.07606844 |
| -2.291388137 | 0.790478877 | 29.13765177 |
| -2.23223549 | 0.77296058 | 28.42133288 |
| -2.239839523 | 0.771369548 | 28.55380594 |
| -2.291388137 | 0.780472815 | 29.26773058 |
| -2.329000334 | 0.785411381 | 29.8107615 |
| -2.328766629 | 0.782559356 | 29.80947435 |
| -2.311400261 | 0.780472815 | 29.44783969 |
| -2.309754981 | 0.788355569 | 29.10731975 |
| -2.343941804 | 0.810377274 | 29.05992614 |
| -2.401454817 | 0.840509186 | 29.21770027 |

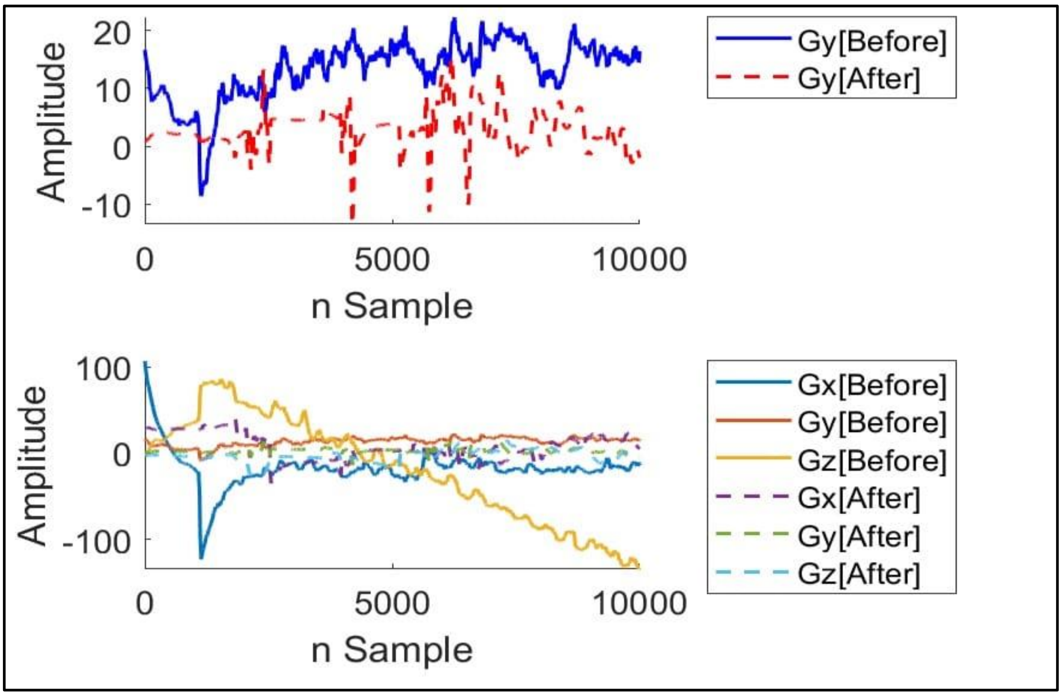


Figure 4.7: Subject 7 Mean and median frequency spectrum of BEFORE and AFTER experiments

Utilizing the proposed electronic equipment and analyzing frequency, mean, and median components, the reduction observed signifies the enhanced stability when using the toothbrush after implementing the learning model. Through the comparative analysis of the movement signals along the X, Y, and Z axes, specific locations can be identified where the toothbrush demonstrates consistent and uniform motion signals, as clearly discerned.

As depicted in Figure (4.7) shown above, the upper section represents Gy, while the lower section represents Gx, Gy, and Gz, depicting the amplitude range of the experiment conducted after implementation. This visualization serves to illustrate the advantages of our model. The average reduction in movement amplitude between the two experiments amounts to 75%, indicating a substantial decrease.

The collected data is undergoing analysis through the MATLAB statistical application to generate visual representations of the movement along all three axes. Following the completion of the data processing,

The Table 4.15 displays signal length samples pertaining to Experiment 1, denoted as the pre-teaching phase (BTE). Additionally, it encompasses samples of Experiment 2, identified in accordance with the teaching mode of the experiment (utilizing the proposed electronic equipment), and labeled as the post-teaching phase (ATE).

Table 4.15: Sample of Subject 08 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 1.19061579 | 0.690357055 | 24.38261076 |
| 1.339760977 | 0.788583157 | 27.56289949 |
| 1.200620965 | 0.730377754 | 24.23253314 |
| 1.167692676 | 0.739111947 | 22.4211974 |
| 1.290667537 | 0.840434675 | 23.9723986 |
| 1.33781936 | 0.896284915 | 24.85627169 |
| 1.260652013 | 0.880455374 | 23.74227958 |
| 1.207821751 | 0.885792345 | 22.97773703 |
| 1.230636489 | 0.950491597 | 23.52216573 |
| 1.233468567 | 1.009425559 | 23.79087588 |
| 1.19061579 | 1.030532995 | 23.25202602 |
| 1.166080316 | 1.046463493 | 22.87259088 |
| 1.19061579 | 1.090564043 | 23.04191735 |
| 1.229983526 | 1.142710688 | 23.06781096 |
| 1.270657188 | 1.180610615 | 22.81179833 |
| 1.306845664 | 1.203397431 | 22.63827638 |
| 1.320683061 | 1.230636489 | 22.67172588 |
| 1.309007787 | 1.262106245 | 22.61542653 |
| 1.320683061 | 1.290667537 | 22.48162756 |

The data presented in (Table 4.16) shown below reflects a subset of 10,000 samples in length. Through the utilization of the proposed electronic equipment, the recorded data from each raw subject was segmented into epochs, with computations conducted for each individual epoch and stored for each subject and experiment. This approach aims to demonstrate the variations in patterns across different trials, leading to the utilization of feature parameters based on temporal and spectral statistics.

The samples included in the Table below illustrate that the primary objective of experiment-2 is to monitor, stabilize, and standardize the movements of the toothbrush (utilizing our proposed electronic equipment) in the balanced position, encompassing the pathways along the X, Y, and Z axes.

Table 4.16: Sample of Subject 08 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -0.32021362 | 6.784526084 | 14.52969303 |
| -0.333616137 | 7.233858257 | 15.51560023 |
| -0.338336268 | 7.537126664 | 16.19365927 |
| -0.334800625 | 7.697271345 | 16.56904752 |
| -0.324002857 | 7.727030926 | 16.66758327 |
| -0.30740213 | 7.647351249 | 16.53241283 |
| -0.28678424 | 7.485131763 | 16.21930134 |
| -0.2640995 | 7.270548248 | 15.79102813 |
| -0.24129348 | 7.034225512 | 15.31146152 |
| -0.220146864 | 6.804539435 | 14.83989997 |
| -0.202037563 | 6.602271973 | 14.42005127 |
| -0.188129912 | 6.447525678 | 14.09397661 |
| -0.179060198 | 6.351048468 | 13.88437647 |
| -0.174999967 | 6.31621726 | 13.79859948 |
| -0.175687857 | 6.339502903 | 13.82960888 |
| -0.180499236 | 6.411564369 | 13.95826742 |
| -0.188544187 | 6.518817466 | 14.15661516 |
| -0.198782101 | 6.645284984 | 14.39173395 |
| -0.210140188 | 6.774519408 | 14.62975979 |

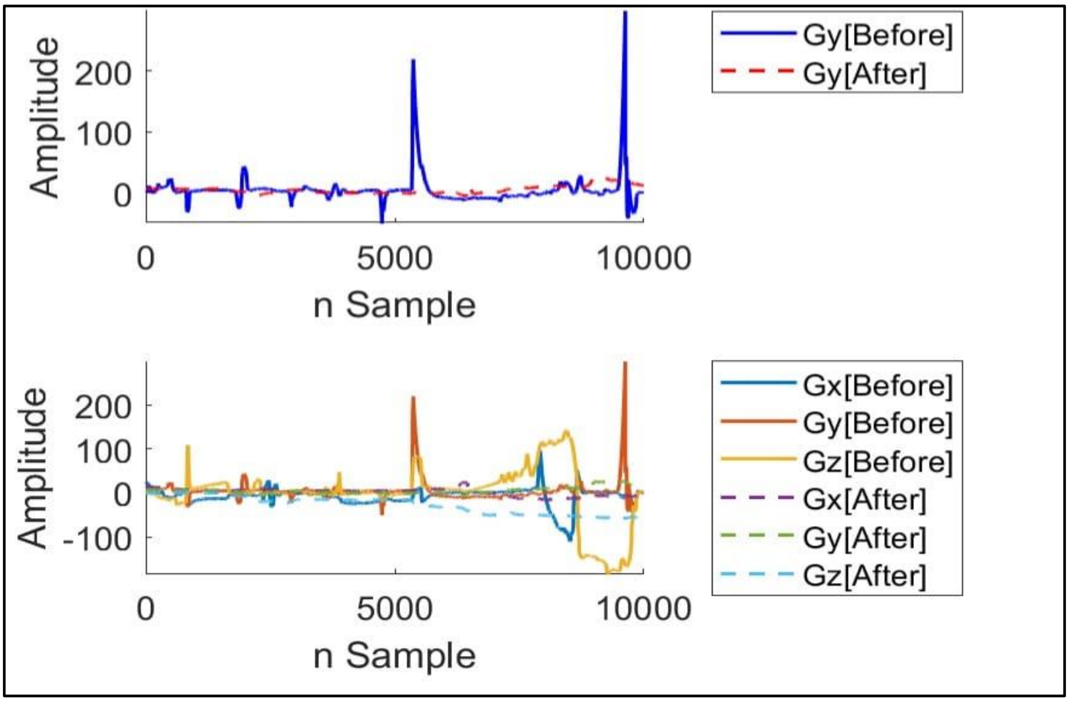


Figure 4.8: Subject 8 Mean and median frequency spectrum of BEFORE and AFTER experiments.

As depicted in Figure (4.8) above, the upper section represents Gy, while the lower section displays Gx, Gy, and Gz, illustrating the amplitude range after the experiment. This visualization underscores the advantages of our model. By comparing the movement signals across the three axes X, Y, and Z, we can identify the specific locations where the toothbrush demonstrates consistent motion signals, a clear and discernible observation.

Through the application of the suggested electronic equipment, the data recorded for each original subject was segmented into epochs, with computations performed for each specific epoch and stored for each subject and experiment. This methodology serves to elucidate the discrepancies in patterns across various trials, utilizing feature parameters rooted in temporal and spectral statistics. This process aims to produce the comprehensive feature set necessary to depict the behavior of each pattern.

The Table 4.17 displays a subset of 10,000 samples in length. Recorded data for each original subject was segmented into epochs utilizing the proposed electronic equipment. Computation was conducted for each specific epoch and the results were stored for each subject and experiment, aiming to elucidate the variations in patterns across different trials. This process involves the utilization of feature parameters rooted in temporal and spectral statistics to generate the comprehensive feature set necessary to represent the behavior of each pattern.

By analyzing the data presented in Table (4.17) below, a subset of the samples from Experiment 1, pertaining to the teaching mode of the experiment, is identified as the "Before-Teaching the Subjects" phase (BTE) based on the length of the subject data.

Table 4.17: Sample of Subject 09 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 6.344241491 | 9.886609769 | -24.51639062 |
| 6.72191488 | 10.46330758 | -25.97994024 |
| 6.988037784 | 10.86354799 | -27.01343714 |
| 7.14389363 | 11.08957067 | -27.62177386 |
| 7.19697983 | 11.15339906 | -27.8338165 |
| 7.160203732 | 11.07556836 | -27.69930809 |
| 7.050715264 | 10.88328336 | -27.28437054 |
| 6.888478243 | 10.60816603 | -26.66599717 |
| 6.694700999 | 10.28378246 | -25.92600051 |
| 6.490255114 | 9.943151085 | -25.1449109 |
| 6.294208041 | 9.616429138 | -24.39631034 |
| 6.119851351 | 9.32586872 | -23.73252455 |
| 5.981552406 | 9.093138147 | -23.20812296 |
| 5.887184588 | 8.930515437 | -22.85333028 |
| 5.840030034 | 8.842958962 | -22.680575 |
| 5.838972546 | 8.828419102 | -22.68522882 |
| 5.879024916 | 8.878682817 | -22.8476429 |
| 5.952125912 | 8.980648482 | -23.13623172 |
| 6.048123336 | 9.117898022 | -23.51128194 |

Due to the data detected in the table below, it is evident that experiment-2, facilitated by our proposed electronic equipment, primarily serves to monitor, stabilize, and regulate the motion of the toothbrush in its equilibrium position, encompassing the X, Y, and Z axes pathways.

The orientations have been established and assigned through statistical analytical procedures captured by our innovative Multidirectional Therapeutic Toothbrush (MTB) (the electronic equipment).

The Table (4.18) shown below presents a selection of 10,000 samples, where the raw data for each subject has been segmented into epochs. Computational analysis has been performed for each individual epoch and the results have been stored for each subject and experiment to elucidate the variations in patterns across different trials. This process involves the utilization of feature parameters rooted in temporal and spectral statistics to generate the comprehensive feature set necessary to depict the behavior of each pattern.

Table 4.18: Sample of Subject 09 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.301394199 | 0.780472815 | 28.99756691 |
| -2.613336625 | 0.892882595 | 32.81480087 |
| -2.546079227 | 0.875836873 | 31.82536557 |
| -2.321406323 | 0.800484939 | 28.88750023 |
| -2.172081428 | 0.744804639 | 26.99522468 |
| -2.192880534 | 0.744497312 | 27.35521937 |
| -2.311400261 | 0.780472815 | 29.01757903 |
| -2.391422134 | 0.809696234 | 30.20470028 |
| -2.370901596 | 0.809961732 | 30.07606844 |
| -2.291388137 | 0.790478877 | 29.13765177 |
| -2.23223549 | 0.77296058 | 28.42133288 |
| -2.239839523 | 0.771369548 | 28.55380594 |
| -2.291388137 | 0.780472815 | 29.26773058 |
| -2.329000334 | 0.785411381 | 29.8107615 |
| -2.328766629 | 0.782559356 | 29.80947435 |
| -2.311400261 | 0.780472815 | 29.44783969 |
| -2.309754981 | 0.788355569 | 29.10731975 |
| -2.343941804 | 0.810377274 | 29.05992614 |
| -2.401454817 | 0.840509186 | 29.21770027 |

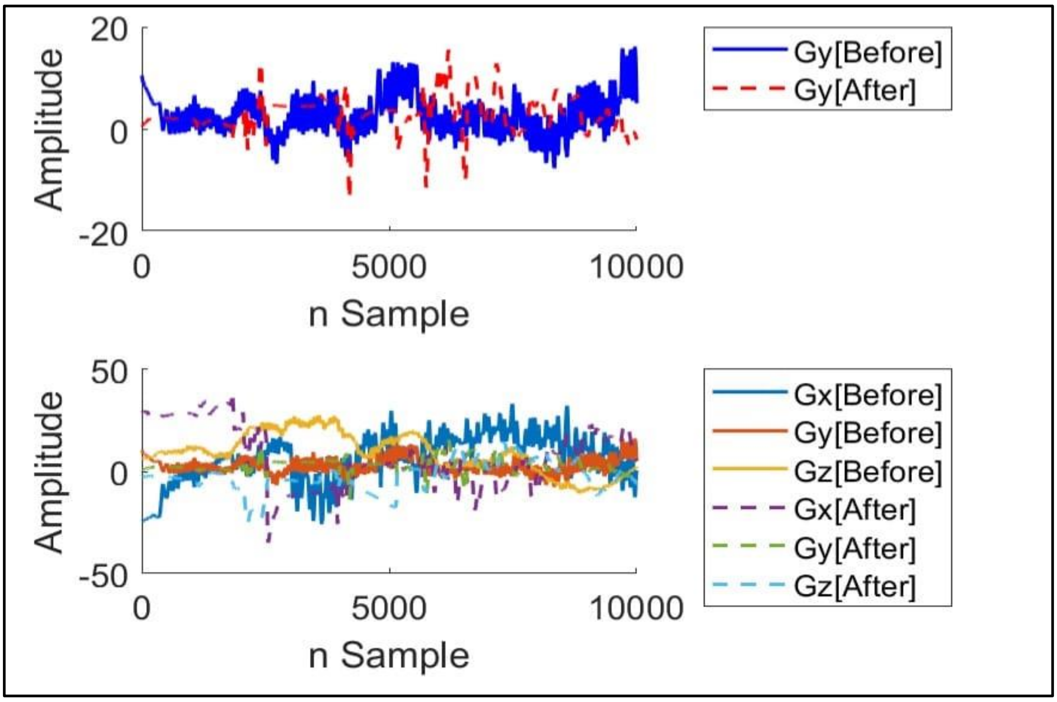


Figure 4.9: Subject 9 Mean and median frequency spectrum of BEFORE and AFTER experiments

As indicated in Figure (4.9) shown above, the upper section represents Gy, while the lower section displays Gx, Gy, and Gz, showcasing the amplitude range after the experiment. This presentation highlights the merits of our model.

Through the frequency recorded with our proposed electronic equipment, the mean and median components reveal a decrease in amplitude, signifying stability in toothbrush usage following the application of the learning model. A comparative analysis of the movement signals along the X, Y, and Z axes enables the identification of specific locations where the toothbrush demonstrates consistent motion patterns.

The collected data is undergoing processing via the MATLAB statistical application to visualize the movements along all three axes.

The Table (4.19) shown below presents the sample lengths of Experiment 1, denoted as BTE (Before Teaching the Subjects Phase), which are determined based on the experiment's teaching mode. Similarly, the sample lengths of Experiment 2 are labeled as ATE (After Teaching the Subjects Phase), as they are detected in accordance with the experiment's teaching mode.

Table 4.19: Sample of Subject 10 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -85.24644735 | 30.86043475 | 6.634393073 |
| -92.15793841 | 33.25595549 | 7.151944195 |
| -96.04414557 | 34.52915394 | 7.431567379 |
| -97.09999627 | 34.75794437 | 7.491041365 |
| -95.82597104 | 34.13255095 | 7.37192585 |
| -92.93688207 | 32.92120885 | 7.131987585 |
| -89.24492461 | 31.42652673 | 6.835686739 |
| -85.5366395 | 29.93982515 | 6.544333439 |
| -82.41325775 | 28.68718408 | 6.303546148 |
| -80.35565529 | 27.83941106 | 6.148612123 |
| -79.5632198 | 27.46513795 | 6.092189269 |
| -79.99068995 | 27.54186997 | 6.127718429 |
| -81.38885344 | 27.97199899 | 6.233158114 |
| -83.37319508 | 28.60912681 | 6.376847666 |
| -85.50661962 | 29.28939446 | 6.524320187 |
| -87.3317564 | 29.84931714 | 6.641092624 |
| -88.57996772 | 30.18726896 | 6.708477859 |
| -89.09363932 | 30.24765556 | 6.717481467 |
| -88.87099472 | 30.03316681 | 6.671666371 |

As shown in the he Table (4.20) shown below, it is evident that the primary objective is to monitor, stabilize the motion of the toothbrush in the balanced position, utilizing the data from the proposed electronic equipment, which encompasses the three axes pathways of (X, Y, and Z).

The Table (4.20) shown below displays a subset of 10,000 signal length samples, wherein the raw subject data has been partitioned into epochs. Computational analysis has been conducted for each participant epoch and the results have been stored for each subject and experiment to elucidate the variations in patterns across different trials. The utilization of feature parameters rooted in temporal and spectral statistics is employed to generate the comprehensive feature set necessary to depict the behavior of each pattern, as detailed in (Table 4.20).

Table 4.20: Sample of Subject 10 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| 5.043354363 | 7.114732048 | 22.94526102 |
| 5.392619575 | 7.626311212 | 24.46972115 |
| 5.600406474 | 7.942362828 | 25.33277364 |
| 5.673048564 | 8.070557777 | 25.56527728 |
| 5.628418116 | 8.034521257 | 25.25155938 |
| 5.493352306 | 7.870351768 | 24.51743362 |
| 5.300195056 | 7.621913595 | 23.51414053 |
| 5.082907816 | 7.33552167 | 22.40030527 |
| 4.87324122 | 7.054692115 | 21.32418283 |
| 4.694759036 | 6.812133216 | 20.39993433 |
| 4.568062988 | 6.636297376 | 19.72042604 |
| 4.50288107 | 6.540992154 | 19.33044806 |
| 4.499867622 | 6.527655943 | 19.23226071 |
| 4.551600011 | 6.586677373 | 19.39031925 |
| 4.644466846 | 6.699942165 | 19.74017713 |
| 4.761137171 | 6.844185137 | 20.2001102 |
| 4.883247876 | 6.994652182 | 20.68375688 |
| 4.991235574 | 7.125148852 | 21.10374842 |
| 5.074147217 | 7.22066482 | 21.40518539 |

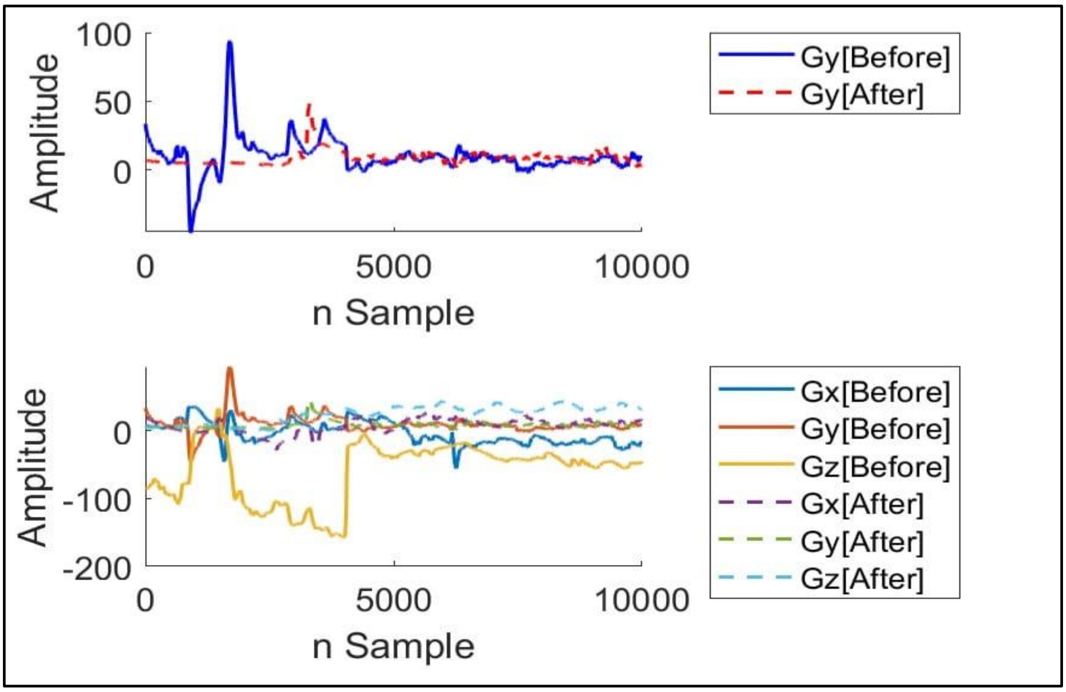


Figure 4.10: Subject 10 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Through the comparison of the movement signals along the X, Y, and Z axes, specific locations where the toothbrush demonstrates consistent motion signals can be identified with precision.

The illustration in Figure (4.10) shown above depicts Gy in the upper section and Gx, Gy, Gz in the lower section, showcasing the amplitude range following the AFTER experiment and highlighting the advantages of our model. Analysis of the frequency using the proposed electronic equipment, along with the mean and median components, indicates a reduction in instability in toothbrush usage after the implementation of the learning model.

In accordance with the experiment's teaching mode, as illustrated in (Table 4.21), which outlines the sample lengths of Experiment 1 identified as BEFOR-Teaching the subjects phase (BTE), and the sample lengths of Experiment 2, designated as AFTER-Teaching the subjects phase (ATE), the data is being analyzed using the MATLAB statistical application to graph the movements across all three axes, utilizing the data obtained from our proposed electronic equipment (Proposed Toothbrush).

Following the completion of the data processing procedure detailed in (Table 4.21), shows the statistical values reveal the recorded data of 23 subjects before and after the educational stage.

Table 4.21: Sample of Subject 11 before training (Sign. of Expt.-1)

| x | y | z |
|---|---|---|
| 7.114732048 | 22.94526102 | 3.001996645 |
| 7.626311212 | 24.46972115 | 3.291834285 |
| 7.942362828 | 25.33277364 | 3.520313205 |
| 8.070557777 | 25.56527728 | 3.688870501 |
| 8.034521257 | 25.25155938 | 3.804635272 |
| 7.870351768 | 24.51743362 | 3.879220659 |
| 7.621913595 | 23.51414053 | 3.927046848 |
| 7.33552167 | 22.40030527 | 3.963425508 |
| 7.054692115 | 21.32418283 | 4.002662193 |
| 6.812133216 | 20.39993433 | 4.049055672 |
| 6.636297376 | 19.72042604 | 4.11674425 |
| 6.540992154 | 19.33044806 | 4.210788439 |
| 6.527655943 | 19.23226071 | 4.332274123 |
| 6.586677373 | 19.39031925 | 4.478636353 |
| 6.699942165 | 19.74017713 | 4.644373934 |
| 6.844185137 | 20.2001102 | 4.822034216 |
| 6.994652182 | 20.68375688 | 5.003327741 |
| 7.125148852 | 21.10374842 | 5.172337523 |
| 7.22066482 | 21.40518539 | 5.328998663 |

The Table (4.22) shown below displays a subset of 10,000 samples in length, with each raw subject's data being segmented into epochs. Computation has been performed for each individual epoch and the results have been stored for each subject and experiment, showcasing the variations in patterns across different trials. The feature parameters based on temporal and spectral statistics are utilized to generate the comprehensive feature set necessary to represent the behavior of each pattern.

It has been emphasized that the primary purpose of utilizing data from the proposed electronic equipment is to monitor, stabilize, and standardize the motion of the toothbrush in its equilibrium position, encompassing the three axes pathways of X, Y, and Z. These directives have been established and tailored through statistical analytical procedures employing our newly proposed multidirectional optimization application (MOA).

Table 4.22: Sample of Subject 11 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| 7.114732048 | 22.94526102 | 3.001996645 |
| 7.626311212 | 24.46972115 | 3.291834285 |
| 7.942362828 | 25.33277364 | 3.520313205 |
| 8.070557777 | 25.56527728 | 3.688870501 |
| 8.034521257 | 25.25155938 | 3.804635272 |
| 7.870351768 | 24.51743362 | 3.879220659 |
| 7.621913595 | 23.51414053 | 3.927046848 |
| 7.33552167 | 22.40030527 | 3.963425508 |
| 7.054692115 | 21.32418283 | 4.002662193 |
| 6.812133216 | 20.39993433 | 4.049055672 |
| 6.636297376 | 19.72042604 | 4.11674425 |
| 6.540992154 | 19.33044806 | 4.210788439 |
| 6.527655943 | 19.23226071 | 4.332274123 |
| 6.586677373 | 19.39031925 | 4.478636353 |
| 6.699942165 | 19.74017713 | 4.644373934 |
| 6.844185137 | 20.2001102 | 4.822034216 |
| 6.994652182 | 20.68375688 | 5.003327741 |
| 7.125148852 | 21.10374842 | 5.172337523 |
| 7.22066482 | 21.40518539 | 5.328998663 |

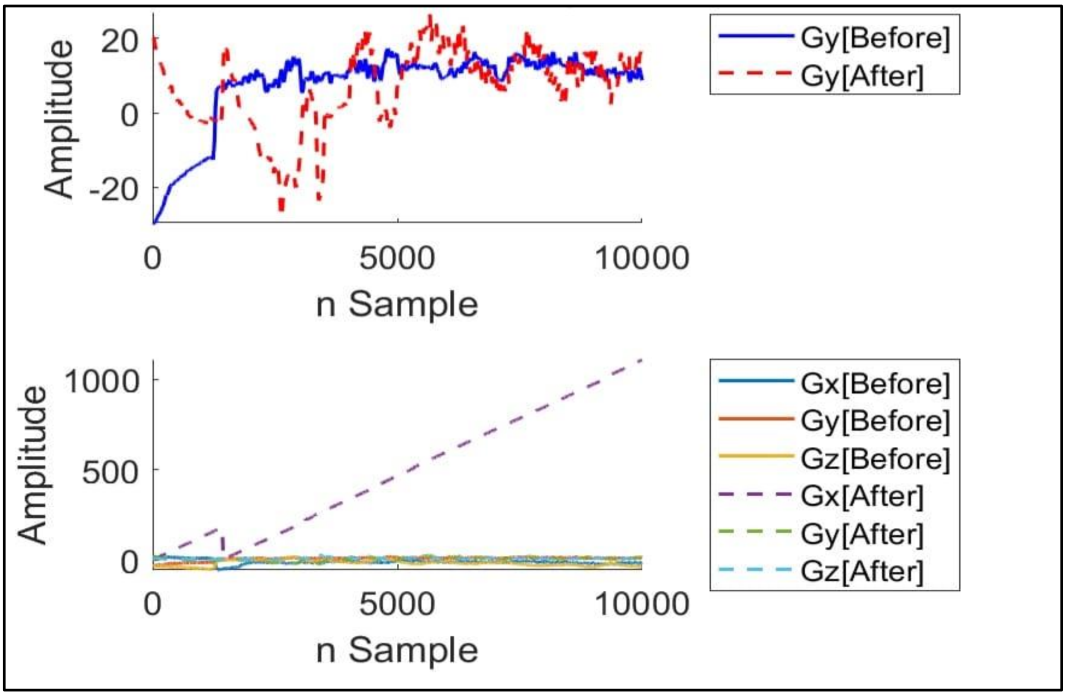


Figure 4.11: Subject 11 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Utilizing the proposed electronic equipment to analyze frequency, the mean and median components reveal a reduction in instability when using the toothbrush following the implementation of the learning model. Through the comparison of the movement signals along the X, Y, and Z axes, specific locations where the toothbrush demonstrates consistent motion signals can be identified with precision.

The Figure (4.11) shown above depicts the (Top) as Gy and (Bottom) as Gx, Gy, Gz, illustrating the amplitude range of the AFTER-experiment. Data captured using the proposed electronic equipment has been analyzed, and feature parameters based on temporal and spectral statistics have been utilized to produce the comprehensive feature set necessary to depict the behavior of each pattern.

The MATLAB statistical application is utilized to analyze the data and generate visual representations of the movements along all three axes, based on the information obtained from the suggested electronic equipment data (Table 4.23).

The Table 4.23 shown below presents the sample durations of Experiment 1, categorized according to the teaching mode of the experiment, denoted as "BEFOR-Teaching the subjects phase" (BTE). Similarly, the sample durations of Experiment 2 are delineated based on the experiment's teaching mode, and referred to as "AFTER-Teaching the subjects phase" (ATE).

Table 4.23: Sample of Subject 12 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -41.94808936 | 11.90797384 | -1.220817486 |
| -44.28004112 | 12.56454576 | -1.334233317 |
| -46.0085945 | 13.04862177 | -1.439652039 |
| -47.13485648 | 13.36056033 | -1.536482589 |
| -47.68830512 | 13.50880682 | -1.624674918 |
| -47.72393569 | 13.50907947 | -1.704686482 |
| -47.31796842 | 13.38314606 | -1.777416816 |
| -46.56243214 | 13.15728069 | -1.844115572 |
| -45.55900662 | 12.86050981 | -1.906271321 |
| -44.41254673 | 12.52276775 | -1.965489778 |
| -43.22472184 | 12.17308505 | -2.023370837 |
| -42.08818317 | 11.83792693 | -2.081393747 |
| -41.06643896 | 11.53587342 | -2.136840314 |
| -40.23339584 | 11.2877032 | -2.194067168 |
| -39.63147009 | 11.1055348 | -2.25410769 |
| -39.28245372 | 10.99559868 | -2.317743057 |
| -39.18790709 | 10.95835012 | -2.385477442 |
| -39.33084749 | 10.98895198 | -2.457528801 |
| -39.67854467 | 11.07807347 | -2.533834488 |

The following Table (4.24) displays a subset of 10,000 samples in duration. Each original subject dataset was segmented into epochs, and calculations were performed for each individual epoch. These results were then stored for each subject and experiment in order to demonstrate the variations in patterns across different trials. The subsequent feature parameters, which are based on temporal and spectral statistics, were utilized for this purpose.

The data shown below in Table 4.24 illustrates the duration of samples for Experiment 1, categorized according to the experiment's teaching mode, referred to as "BEFOR-Teaching the subjects phase" (BTE). Similarly, the duration of samples for Experiment 2 is determined based on the experiment's teaching mode and is designated as "AFTER-Teaching the subjects phase" (ATE).

Table 4.24: Sample of Subject 12 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.301394199 | 0.780472815 | 28.99756691 |
| -2.613336625 | 0.892882595 | 32.81480087 |
| -2.546079227 | 0.875836873 | 31.82536557 |
| -2.321406323 | 0.800484939 | 28.88750023 |
| -2.172081428 | 0.744804639 | 26.99522468 |
| -2.192880534 | 0.744497312 | 27.35521937 |
| -2.311400261 | 0.780472815 | 29.01757903 |
| -2.391422134 | 0.809696234 | 30.20470028 |
| -2.370901596 | 0.809961732 | 30.07606844 |
| -2.291388137 | 0.790478877 | 29.13765177 |
| -2.23223549 | 0.77296058 | 28.42133288 |
| -2.239839523 | 0.771369548 | 28.55380594 |
| -2.291388137 | 0.780472815 | 29.26773058 |
| -2.329000334 | 0.785411381 | 29.8107615 |
| -2.328766629 | 0.782559356 | 29.80947435 |
| -2.311400261 | 0.780472815 | 29.44783969 |
| -2.309754981 | 0.788355569 | 29.10731975 |
| -2.343941804 | 0.810377274 | 29.05992614 |
| -2.401454817 | 0.840509186 | 29.21770027 |

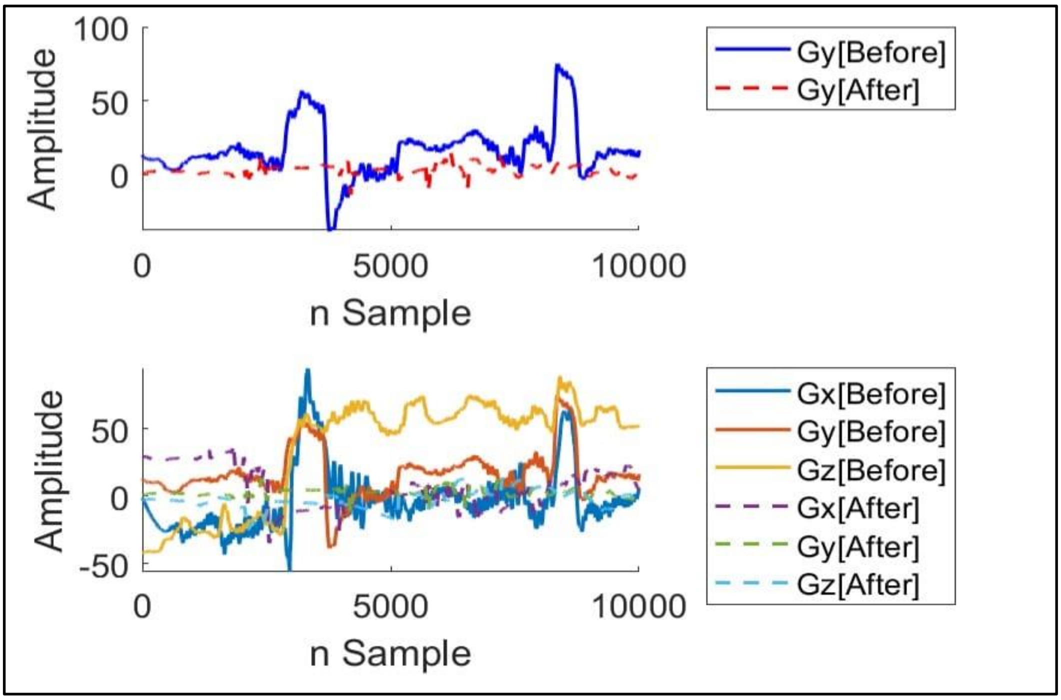


Figure 4.12: Subject 12 Mean and median frequency spectrum of BEFORE and AFTER experiments.

By conducting a comparative analysis of the movement signals across the three axes X, Y, and Z, we are able to identify specific instances where the toothbrush demonstrates consistent motion signals, as evident from the data. The above Figure (4.12) depicts the representation of Gy in the top section and Gx, Gy, and Gz in the bottom section, showcasing the amplitude range following the experiment. This visualization highlights the benefits of our model.

It is important to emphasize the generation of a comprehensive feature set necessary for representing the behavior of each pattern. Consequently, the statistical findings reveal the recordings of data from 23 subjects before and after the education phase, utilizing the proposed electronic equipment data. The Mean and Median components derived from the recorded frequency (using the proposed electronic equipment) indicate a reduction in instability when using the toothbrush subsequent to the application of the learning model.

The primary objective of employing the proposed electronic equipment data analyzer is to monitor, stabilize, and standardize the motion of the toothbrush in its balanced state, encompassing the X, Y, and Z axes pathways. These orientations have been configured and specified through statistical analytical procedures utilizing our innovative Multidirectional Therapeutic Toothbrush (MTB) as part of a multiphase optimization application (MOA).

As in the Table (4.25) shown below presents a subset of 10,000 samples in duration, with each original subject dataset segmented into epochs and analyzed for each participant's epoch, demonstrating the variations in patterns across different trials.

The feature parameters derived from temporal and spectral statistics are utilized to produce the comprehensive feature set necessary for depicting the behavior of each pattern.

Table 4.25: Sample of Subject 13 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -31.56117946 | -30.73062211 | 14.65983764 |
| -33.06960575 | -32.17430066 | 15.32766367 |
| -34.25478339 | -33.29784644 | 15.8404367 |
| -35.11479428 | -34.09936903 | 16.19799836 |
| -35.65892647 | -34.58800421 | 16.40557119 |
| -35.90690825 | -34.7831694 | 16.47337276 |
| -35.88770921 | -34.7133947 | 16.41602214 |
| -35.63797278 | -34.41479235 | 16.25177052 |
| -35.20016149 | -33.92924375 | 16.00159529 |
| -34.62050867 | -33.3023955 | 15.68820324 |
| -33.9468777 | -32.58156297 | 15.33499178 |
| -33.22663244 | -31.81364259 | 14.96501816 |
| -32.5046194 | -31.0431308 | 14.60002538 |
| -31.82135405 | -30.31034007 | 14.25956903 |
| -31.20112972 | -29.64152906 | 13.95583675 |
| -30.68048183 | -29.07165365 | 13.70580755 |
| -30.27990591 | -28.62139231 | 13.51908008 |
| -30.01186919 | -28.30352695 | 13.40130043 |
| -29.88080385 | -28.12292335 | 13.35417197 |

As depicted below, the data is undergoing processing through the statistical capabilities of MATLAB to visualize the movement across all three axes using the proposed electronic equipment data analyzer. Following the completion of the data processing, statistical values reveal the data recorded from 23 subjects before and after the educational phase.

The Table (4.26) shown below displays the sample lengths of Experiment 1, categorized according to the experiment's teaching mode, denoted as the "Before-Teaching the Subjects" phase (BTE), and Experiment 2, categorized based on the experiment's teaching mode, labeled as the "After-Teaching the Subjects" phase (ATE).

Table 4.26: Sample of Subject 13 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.301394199 | 0.780472815 | 28.99756691 |
| -2.613336625 | 0.892882595 | 32.81480087 |
| -2.546079227 | 0.875836873 | 31.82536557 |
| -2.321406323 | 0.800484939 | 28.88750023 |
| -2.172081428 | 0.744804639 | 26.99522468 |
| -2.192880534 | 0.744497312 | 27.35521937 |
| -2.311400261 | 0.780472815 | 29.01757903 |
| -2.391422134 | 0.809696234 | 30.20470028 |
| -2.370901596 | 0.809961732 | 30.07606844 |
| -2.291388137 | 0.790478877 | 29.13765177 |
| -2.23223549 | 0.77296058 | 28.42133288 |
| -2.239839523 | 0.771369548 | 28.55380594 |
| -2.291388137 | 0.780472815 | 29.26773058 |
| -2.329000334 | 0.785411381 | 29.8107615 |
| -2.328766629 | 0.782559356 | 29.80947435 |
| -2.311400261 | 0.780472815 | 29.44783969 |
| -2.309754981 | 0.788355569 | 29.10731975 |
| -2.343941804 | 0.810377274 | 29.05992614 |
| -2.401454817 | 0.840509186 | 29.21770027 |

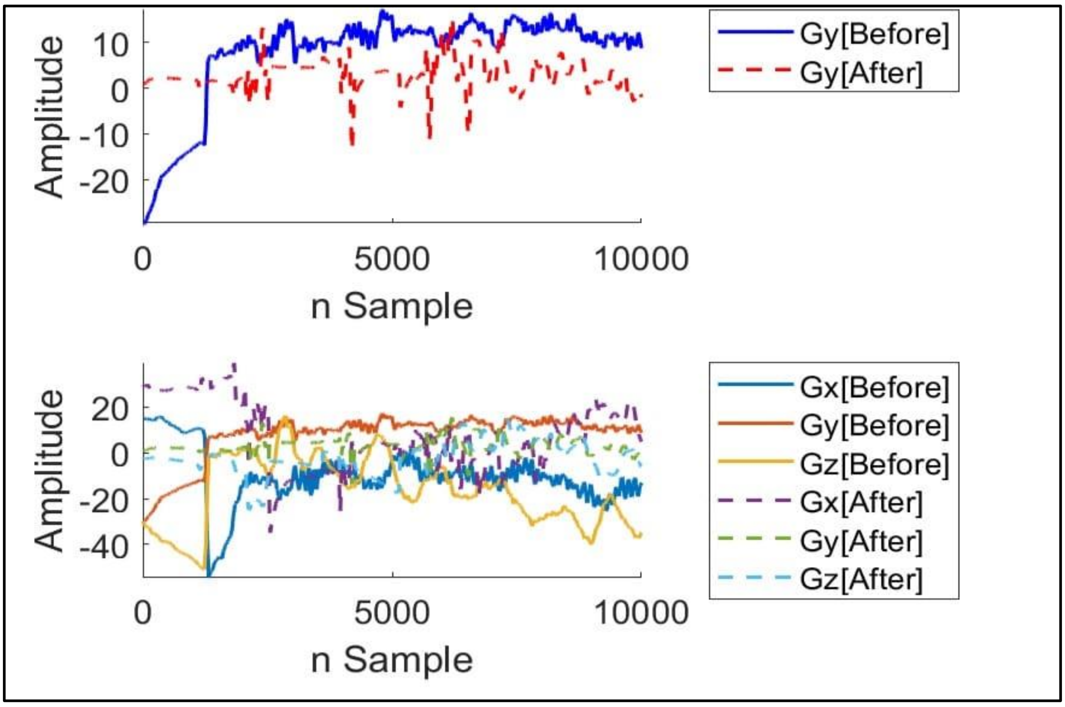


Figure 4.13: Subject 13 Mean and median frequency spectrum of BEFORE and AFTER experiments

Based on frequency (using proposed electronic equipment), mean and median components indicate the decrease of unstability in using the toothbrush after applying the learning model. By comparing the three axes X, Y, Z of the movement signals, we can pinpoint the locations where the toothbrush exhibits uniform motion signals, as clearly detected.

Figure (4.13) above shows, the (Top) represents Gy. (Bottom) Gx, Gy, Gz. the amplitude-range of AFTER-experiment. It shows the advantage of our model. The average change between the two experiments in range of 75% as reducing the movement amplitude.

It has been emphasized that the primary purpose of utilizing the suggested electronic equipment data analyzer is to monitor, stabilize, and standardize the movement of the toothbrush in its balanced position, encompassing the X, Y, and Z axes pathways. These orientations have been established and tailored through statistical analytical procedures using our innovative Multidirectional Therapeutic Toothbrush (MTB) as part of a multiphase optimization application (MOA).

The Table (4.27) shown below presents a set of 10,000 samples, each computed for individual participant experiments and stored to demonstrate the variations in patterns across different trials. These feature parameters, derived from temporal and spectral statistics, are utilized to create the comprehensive feature set necessary for representing the behavior of each pattern.

Table 4.27: Sample of Subject 14 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -7.104757501 | 7.645119339 | 4.483001916 |
| -7.501161654 | 8.07030741 | 4.728010562 |
| -7.795838215 | 8.385357361 | 4.907911849 |
| -7.988994801 | 8.590398354 | 5.022972405 |
| -8.085620898 | 8.690734435 | 5.076510341 |
| -8.095000818 | 8.69632983 | 5.074578421 |
| -8.029984329 | 8.621031831 | 5.025492999 |
| -7.90606852 | 8.481588097 | 4.93924325 |
| -7.740355966 | 8.296527743 | 4.826822561 |
| -7.550460994 | 8.08498303 | 4.699528155 |
| -7.353437453 | 7.865530414 | 4.568275936 |
| -7.164797705 | 7.65512604 | 4.442975113 |
| -6.995290214 | 7.465307063 | 4.330583842 |
| -6.857099148 | 7.309757529 | 4.238755596 |
| -6.757222079 | 7.196335758 | 4.171903586 |
| -6.699182211 | 7.129146789 | 4.132213436 |
| -6.683105553 | 7.108605293 | 4.119699126 |
| -6.70601656 | 7.131734383 | 4.132398613 |
| -6.762319462 | 7.192666614 | 4.166687648 |

The data is undergoing processing through MATLAB to visualize the movement across all three axes using the proposed electronic equipment data analyzer (Table 4.28).

The Table (4.28) shown below displays the sample lengths of Experiment 1, categorized according to the experiment's teaching mode, denoted as the "Before-Teaching the Subjects" phase (BTE). In a similar manner, the sample lengths of Experiment 2 are categorized based on the experiment's teaching mode, labeled as the "After-Teaching the Subjects" phase (ATE).

Table 4.28: Sample of Subject 14 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.301394199 | 0.780472815 | 28.99756691 |
| -2.613336625 | 0.892882595 | 32.81480087 |
| -2.546079227 | 0.875836873 | 31.82536557 |
| -2.321406323 | 0.800484939 | 28.88750023 |
| -2.172081428 | 0.744804639 | 26.99522468 |
| -2.192880534 | 0.744497312 | 27.35521937 |
| -2.311400261 | 0.780472815 | 29.01757903 |
| -2.391422134 | 0.809696234 | 30.20470028 |
| -2.370901596 | 0.809961732 | 30.07606844 |
| -2.291388137 | 0.790478877 | 29.13765177 |
| -2.23223549 | 0.77296058 | 28.42133288 |
| -2.239839523 | 0.771369548 | 28.55380594 |
| -2.291388137 | 0.780472815 | 29.26773058 |
| -2.329000334 | 0.785411381 | 29.8107615 |
| -2.328766629 | 0.782559356 | 29.80947435 |
| -2.311400261 | 0.780472815 | 29.44783969 |
| -2.309754981 | 0.788355569 | 29.10731975 |
| -2.343941804 | 0.810377274 | 29.05992614 |
| -2.401454817 | 0.840509186 | 29.21770027 |

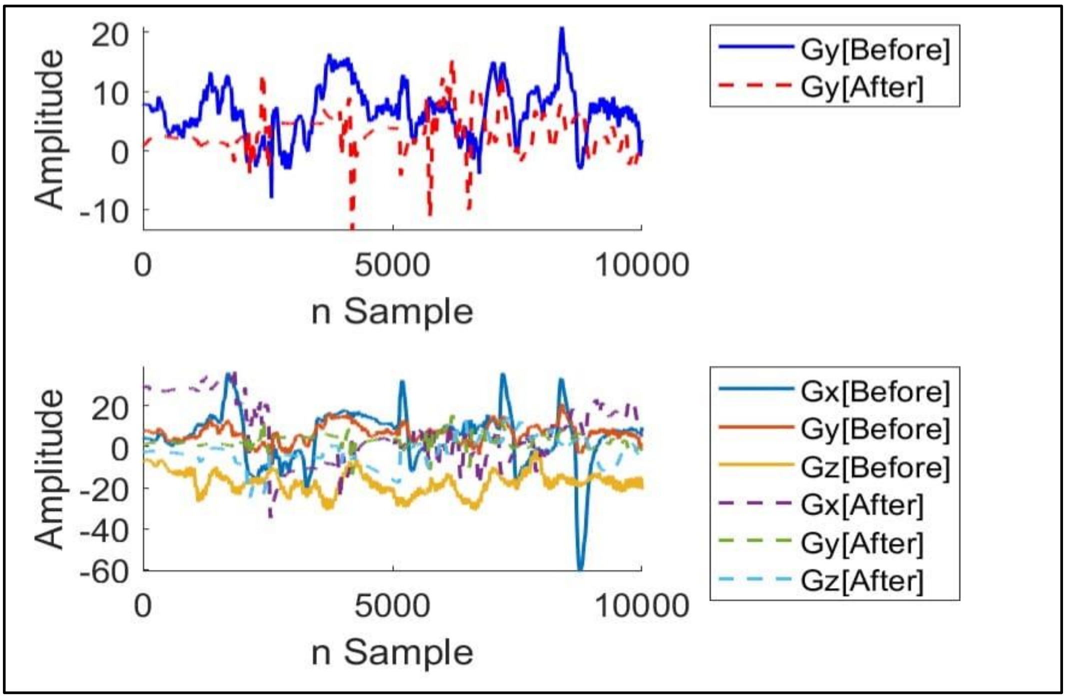


Figure 4.14: Subject 14 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Based on analyzing the movement signals across the three axes X, Y, and Z, we are able to identify specific locations where the toothbrush demonstrates consistent motion signals, as evident.

The figure (4.14) shown below depicts the (Top) representing Gy, and the (Bottom) showing Gx, Gy, and Gz, illustrating the amplitude range of the AFTER experiment, thereby highlighting the benefits of our model. The average reduction of movement amplitude between the two experiments is approximately 75%, as indicated by the frequency-based Mean and Median components (using the proposed electronic equipment), signifying the enhanced stability in toothbrush usage following the implementation of the learning model.

The Table (4.29) shown below presents a subset of 10,000 samples, each of considerable length. Every raw dataset from the subjects was segmented into epochs, computed individually for each epoch, and stored for each subject and experiment to demonstrate the variations in patterns across different trials. The employed feature parameters, based on temporal and spectral statistics, serve to illustrate these differences. It is emphasized that the primary function of the proposed electronic equipment data analyzer is to monitor, stabilize, and standardize the motion of the toothbrush in its balanced position, encompassing the X, Y, and Z axes pathways.

Table 4.29: Sample of Subject 15 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -1.56104531 | -4.062720486 | -29.39968667 |
| -1.652724539 | -4.276889106 | -31.00653786 |
| -1.722684456 | -4.431086278 | -32.18535652 |
| -1.770764768 | -4.525929112 | -32.93766219 |
| -1.797821704 | -4.56484989 | -33.28509311 |
| -1.805635127 | -4.553783113 | -33.26736375 |
| -1.79676411 | -4.500710423 | -32.93920353 |
| -1.774361593 | -4.415096652 | -32.36650019 |
| -1.741961148 | -4.307256967 | -31.62191981 |
| -1.703250414 | -4.187698862 | -30.78030399 |
| -1.661846179 | -4.066483293 | -29.91415173 |
| -1.621085514 | -3.952646779 | -29.08947895 |
| -1.583474675 | -3.852432848 | -28.35169847 |
| -1.551606901 | -3.772609798 | -27.75322718 |
| -1.527102739 | -3.716908752 | -27.32418242 |
| -1.510854446 | -3.686963363 | -27.0799759 |
| -1.50302955 | -3.682385901 | -27.02160221 |
| -1.503120813 | -3.700973932 | -27.13684788 |
| -1.510036661 | -3.739026039 | -27.40228634 |

The data is being analyzed using the MATLAB statistical application to visualize the movement across the three axes through the utilization of the proposed electronic equipment data analyzer, as depicted in (Table 4.30). Upon completion of the data processing, the statistical values reveal the data recorded from 23 subjects both before and after the educational phase.

The Table (4.30) displays the sample lengths of Experiment 1, categorized according to the experiment's teaching mode, denoted as the "Before-Teaching the Subjects" phase (BTE). Similarly, the sample lengths of Experiment 2 are categorized based on the experiment's teaching mode, labeled as the "After-Teaching the Subjects" phase (ATE).

Table 4.30: Sample of Subject 15 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -1.56104531 | -4.062720486 | -29.39968667 |
| -1.652724539 | -4.276889106 | -31.00653786 |
| -1.722684456 | -4.431086278 | -32.18535652 |
| -1.770764768 | -4.525929112 | -32.93766219 |
| -1.797821704 | -4.56484989 | -33.28509311 |
| -1.805635127 | -4.553783113 | -33.26736375 |
| -1.79676411 | -4.500710423 | -32.93920353 |
| -1.774361593 | -4.415096652 | -32.36650019 |
| -1.741961148 | -4.307256967 | -31.62191981 |
| -1.703250414 | -4.187698862 | -30.78030399 |
| -1.661846179 | -4.066483293 | -29.91415173 |
| -1.621085514 | -3.952646779 | -29.08947895 |
| -1.583474675 | -3.852432848 | -28.35169847 |
| -1.551606901 | -3.772609798 | -27.75322718 |
| -1.527102739 | -3.716908752 | -27.32418242 |
| -1.510854446 | -3.686963363 | -27.0799759 |
| -1.50302955 | -3.682385901 | -27.02160221 |
| -1.503120813 | -3.700973932 | -27.13684788 |
| -1.510036661 | -3.739026039 | -27.40228634 |

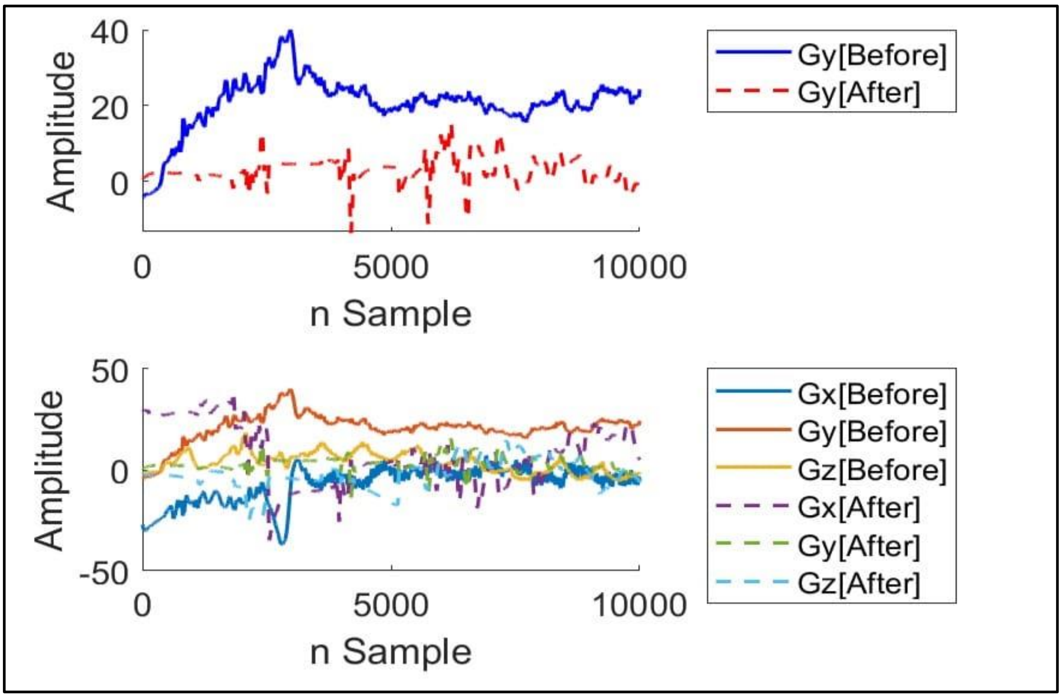


Figure 4.15: Subject 15 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Figure (4.15) depicted above illustrates the amplitude range of the AFTER-experiment, with the (Top) representing Gy and the (Bottom) showcasing Gx, Gy, and Gz. This portrayal highlights the advantages of our model as the average reduction in movement amplitude between the two experiments amounts to approximately 75%. Moreover, it enables individuals with special needs and those with diminished motor skills to address their toothbrushing deficiencies accurately.

Furthermore, these associated behavioral tooth brushing skills could potentially be monitored and assessed to minimize errors. The decrease in frequency, as indicated by the mean and median components using the proposed electronic equipment, signifies the enhanced stability in toothbrush usage following the implementation of the learning model.

It is asserted that the primary purpose of utilizing the proposed electronic equipment data analyzer is to monitor, stabilize, and standardize the motion of the toothbrush in its balanced position, encompassing the X, Y, and Z axes pathways. These orientations have been established and tailored through statistical analytical procedures facilitated by our innovative Multidirectional Therapeutic Toothbrush (MTB). This is achieved through a monitoring multiphase optimization application (MOA).

As shown below in the Table 4.31 several samples of considerable length. Each raw data from the subjects has been segmented into epochs, computed for each participant's epoch, and stored for each subject and experiment to demonstrate the variations in patterns across different trials. The employed feature parameters are based on temporal and spectral statistics.

Table 4.31: Sample of Subject 16 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 20.47370964 | 37.60518125 | -7.024703895 |
| 21.60125899 | 39.65991027 | -7.433496856 |
| 22.43265638 | 41.16577309 | -7.74537656 |
| 22.96884708 | 42.12410686 | -7.960453735 |
| 23.22470386 | 42.56191051 | -8.083509826 |
| 23.22760597 | 42.52925438 | -8.123534213 |
| 23.01531166 | 42.09539208 | -8.093021954 |
| 22.63327985 | 41.34385859 | -8.007083462 |
| 22.13163015 | 40.36690088 | -7.882429107 |
| 21.56195031 | 39.25962277 | -7.73629887 |
| 20.97416501 | 38.11423552 | -7.585409098 |
| 20.41366944 | 37.01478591 | -7.444985325 |
| 19.91107184 | 36.02112871 | -7.323068995 |
| 19.50270114 | 35.19849751 | -7.23379065 |
| 19.20906731 | 34.58526722 | -7.184295072 |
| 19.0405121 | 34.2010931 | -7.178370686 |
| 18.99742288 | 34.04728108 | -7.216492522 |
| 19.07108406 | 34.10833469 | -7.296073893 |
| 19.24507197 | 34.35450655 | -7.411897668 |

The data is undergoing analysis using MATLAB to evaluate the movement across all three axes through the utilization of the proposed electronic equipment data analyzer, as depicted in the (Table 4.32). Following the completion of the data processing, the statistical values reveal the data recorded from 23 subjects both before and after the educational phase.

The Table (4.32) displays the sample lengths of Experiment 1, categorized according to the experiment's teaching mode, denoted as the "Before-Teaching the Subjects" phase (BTE). Samples of 10000 in length have been computed for each participant's experiment and stored to demonstrate the variations in patterns across different trials. The feature parameters employed are based on temporal and spectral statistics, aimed at generating the comprehensive feature set necessary to represent the behavior of each pattern.

Table 4.32: Sample of Subject 16 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.301394199 | 0.780472815 | 28.99756691 |
| -2.613336625 | 0.892882595 | 32.81480087 |
| -2.546079227 | 0.875836873 | 31.82536557 |
| -2.321406323 | 0.800484939 | 28.88750023 |
| -2.172081428 | 0.744804639 | 26.99522468 |
| -2.192880534 | 0.744497312 | 27.35521937 |
| -2.311400261 | 0.780472815 | 29.01757903 |
| -2.391422134 | 0.809696234 | 30.20470028 |
| -2.370901596 | 0.809961732 | 30.07606844 |
| -2.291388137 | 0.790478877 | 29.13765177 |
| -2.23223549 | 0.77296058 | 28.42133288 |
| -2.239839523 | 0.771369548 | 28.55380594 |
| -2.291388137 | 0.780472815 | 29.26773058 |
| -2.329000334 | 0.785411381 | 29.8107615 |
| -2.328766629 | 0.782559356 | 29.80947435 |
| -2.311400261 | 0.780472815 | 29.44783969 |
| -2.309754981 | 0.788355569 | 29.10731975 |
| -2.343941804 | 0.810377274 | 29.05992614 |
| -2.401454817 | 0.840509186 | 29.21770027 |

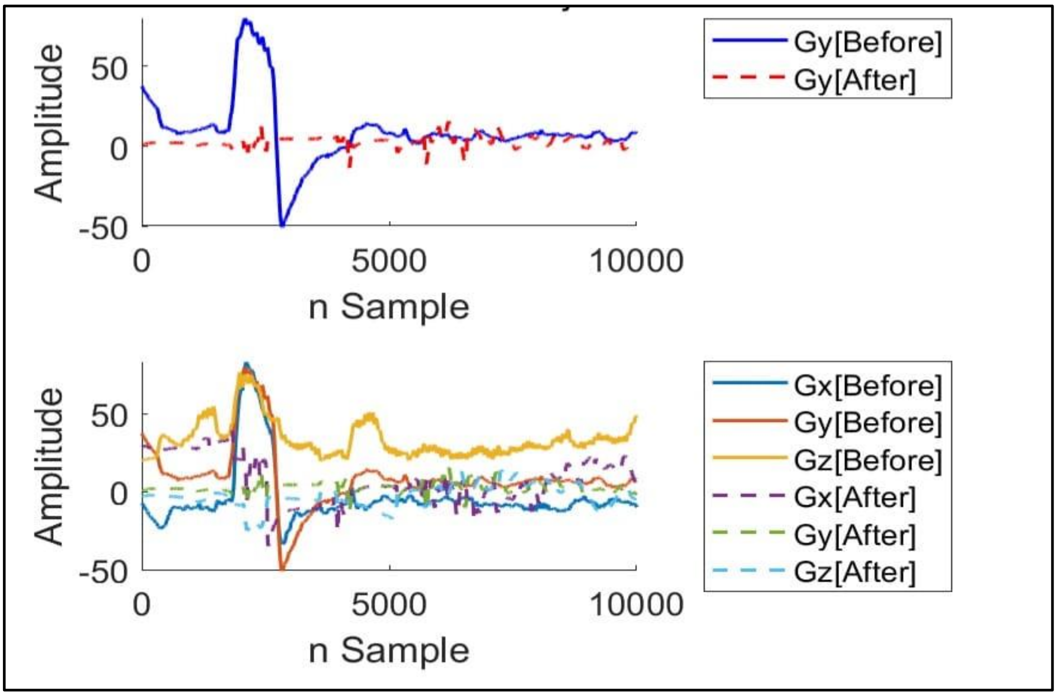


Figure 4.16: Subject 16 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Based on examining the movement signals across the three axes of X, Y, and Z, we are able to identify specific locations where the toothbrush demonstrates consistent motion signals, which are distinctly discernible.

Figure (4.16) shown above depicted above illustrates the amplitude range of the AFTER-experiment, with the (Top) representing Gy and the (Bottom) showcasing Gx, Gy, and Gz. This representation highlights the advantages of our model. Furthermore, the decrease indicated by the Mean and Median components based on frequency (utilizing the proposed electronic equipment) signifies enhanced stability in toothbrush usage following the application of the learning model.

The samples detailed in (Table 4.33) shown below consist of several raw participant data samples, each of 10000 in length, which have been segmented into epochs, computed for each participant's epoch, and stored to demonstrate the variations in patterns across different trials. This analysis is based on the utilization of temporal and spectral statistics.

The proposed electronic equipment data analyzer has been employed to configure and allocate the three axes pathways of X, Y, and Z, utilizing statistical analytical processes facilitated by our innovative Multidirectional Therapeutic Toothbrush (MTB).

Table 4.33: Sample of Subject 17 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 29.33970337 | 3.922634284 | -24.67657179 |
| 30.63742697 | 4.084648805 | -25.78817231 |
| 31.67300417 | 4.209853968 | -26.68241711 |
| 32.44392955 | 4.298074174 | -27.35691823 |
| 32.95555685 | 4.350228449 | -27.8158149 |
| 33.22066702 | 4.368266033 | -28.06942122 |
| 33.25877007 | 4.355065015 | -28.13365235 |
| 33.09517339 | 4.314298715 | -28.02925663 |
| 32.75985892 | 4.250275804 | -27.78088838 |
| 32.28621817 | 4.167761127 | -27.41606196 |
| 31.70969973 | 4.071784918 | -26.96403251 |
| 31.06642608 | 3.967448376 | -26.45465022 |
| 30.39183667 | 3.859733612 | -25.91723559 |
| 29.71941205 | 3.753325564 | -25.37952094 |
| 29.07952864 | 3.652452841 | -24.86669948 |
| 28.49026448 | 3.559941422 | -24.39360999 |
| 27.98020381 | 3.479437252 | -23.98418633 |
| 27.56591605 | 3.413162963 | -23.6522733 |
| 27.25843324 | 3.362548582 | -23.40714966 |

The statistical processing of the data is being conducted through the application of MATLAB, and the plotting of all three-axis movements has been carried out using the proposed electronic equipment data analyzer, as evidenced in (Table 4.34).

The Table (4.34) shown below presented below showcases the sample lengths of Experiment 1, categorized according to the experiment's teaching mode, referred to as the "Before-Teaching the Subjects" phase (BTE). Similarly, the sample lengths of Experiment 2 are categorized based on the experiment's teaching mode and defined as the "After-Teaching the Subjects" phase (ATE).

Table 4.34: Sample of Subject 17 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -1.300827535 | 4.652960028 | -8.755569945 |
| -1.453691195 | 5.198180411 | -9.780393727 |
| -1.472918514 | 5.264841361 | -9.901216311 |
| -1.400645065 | 5.003631142 | -9.39983362 |
| -1.300827535 | 4.642953662 | -8.705538116 |
| -1.228811643 | 4.380104007 | -8.191885421 |
| -1.214027371 | 4.319598708 | -8.057867763 |
| -1.251113078 | 4.441911601 | -8.270069744 |
| -1.3108339 | 4.642953662 | -8.635493557 |
| -1.357688429 | 4.797257748 | -8.920424965 |
| -1.371918442 | 4.836341333 | -8.994510375 |
| -1.354030896 | 4.764324839 | -8.862252695 |
| -1.320840266 | 4.642953662 | -8.635493557 |
| -1.291789703 | 4.542051967 | -8.442709105 |
| -1.281497978 | 4.512461793 | -8.376183312 |
| -1.291057818 | 4.555335661 | -8.437059736 |
| -1.3108339 | 4.632947296 | -8.555442632 |
| -1.326281613 | 4.690632759 | -8.632446446 |
| -1.330079468 | 4.700934192 | -8.619150713 |

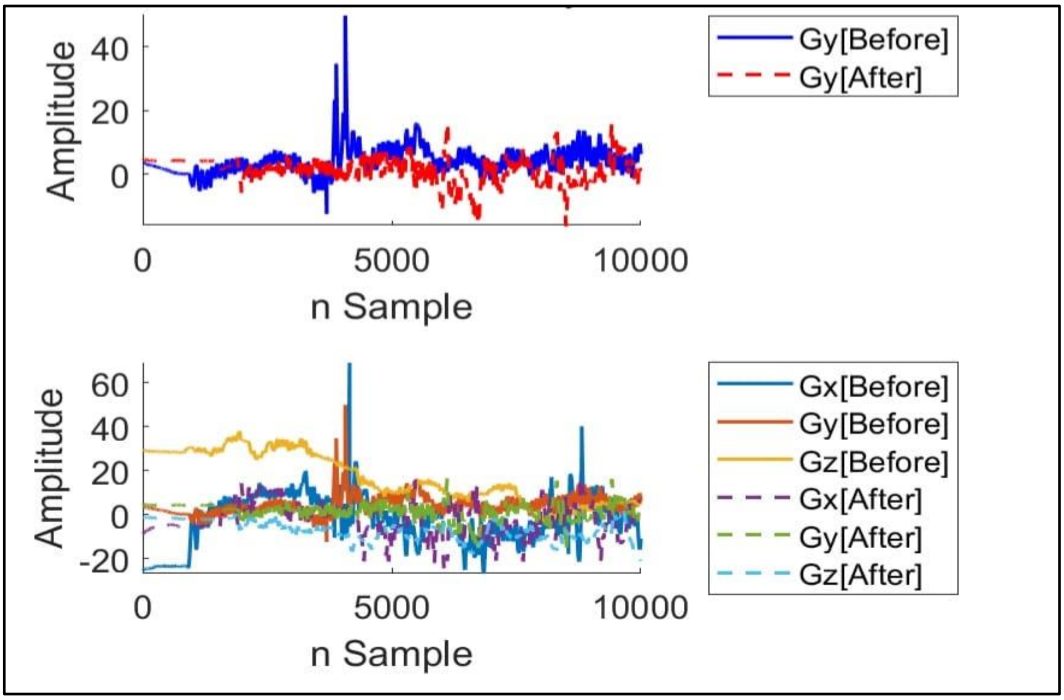


Figure 4.17: Subject 17 Mean and median frequency spectrum of BEFORE and AFTER experiments.

It has been observed that through the comparison of the movement signals across the three axes X, Y, and Z, specific locations where the toothbrush demonstrates consistent motion signals can be identified with clarity.

The Figure (4.17) shown above depicted above illustrates the amplitude range of the AFTER-experiment, with the (Top) representing Gy and the (Bottom) showcasing Gx, Gy, and Gz. This presentation highlights the benefits of our model. The average reduction in movement amplitude between the two experiments is approximately 75%, as indicated by the Mean and Median components based on frequency (utilizing the proposed electronic equipment), signifying increased stability in toothbrush usage following the application of the learning model.

The Table (4.35) shown below presented below displays a series of samples designed to capture the comprehensive feature set necessary to portray the behavior of each pattern. Consequently, the principal role of the proposed electronic equipment data analyzer is to track, stabilize, and standardize the motion of the toothbrush in its equilibrium position, encompassing the three axes pathways of X, Y, and Z.

Table 4.35: Sample of Subject 18 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -1.030692171 | -8.235530652 | -33.22231077 |
| -1.083313775 | -8.611015446 | -34.69934094 |
| -1.127704069 | -8.914548831 | -35.88044959 |
| -1.163639247 | -9.145231615 | -36.76262038 |
| -1.191140844 | -9.304321605 | -37.3517088 |
| -1.210465416 | -9.395119483 | -37.66196105 |
| -1.222085871 | -9.422781573 | -37.71523266 |
| -1.226665437 | -9.394068428 | -37.53994326 |
| -1.225025466 | -9.317040656 | -37.16981508 |
| -1.218108562 | -9.200715419 | -36.64245037 |
| -1.206938643 | -9.054698427 | -35.99780883 |
| -1.192579673 | -8.888806953 | -35.27664928 |
| -1.176094774 | -8.71269945 | -34.51899955 |
| -1.1585074 | -8.535526683 | -33.76271612 |
| -1.140766093 | -8.365618013 | -33.04218981 |
| -1.123396781 | -8.208027369 | -32.37807941 |
| -1.107388045 | -8.070591745 | -31.80271732 |
| -1.093324799 | -7.957934554 | -31.33499049 |
| -1.081638888 | -7.87318381 | -30.98754944 |

Based on the processed data utilized for plotting the movements across all three axes as in the (Table 4.36) shown below presents the statistical outcomes following the completion of the data processing procedure are detected using the proposed electronic equipment, categorized according to the experiment's teaching mode, and defined as the "Before-Teaching the Subjects" phase (BTE). Similarly, the sample lengths of Experiment 2 are detected based on the experiment's teaching mode and defined as the "After-Teaching the Subjects" phase (ATE).

Table 4.36: Sample of Subject 18 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -7.434945024 | 3.762502461 | -39.63636237 |
| -7.970643076 | 4.037516819 | -42.44916445 |
| -8.302483345 | 4.210448962 | -44.16532348 |
| -8.438530465 | 4.285242775 | -44.83006117 |
| -8.40349962 | 4.274200173 | -44.57787861 |
| -8.235111557 | 4.196153792 | -43.61281671 |
| -7.979166498 | 4.073996225 | -42.18187101 |
| -7.683984696 | 3.931891417 | -40.54505465 |
| -7.394918402 | 3.792522428 | -38.94590314 |
| -7.145745071 | 3.672690024 | -37.5677706 |
| -6.966201594 | 3.587339961 | -36.56730442 |
| -6.870544164 | 3.543614889 | -36.01931597 |
| -6.860105509 | 3.542200638 | -35.92897109 |
| -6.924682555 | 3.578022839 | -36.23951105 |
| -7.045206807 | 3.641584615 | -36.84687003 |
| -7.197256286 | 3.720723637 | -37.61878041 |
| -7.35489178 | 3.802529083 | -38.4155504 |
| -7.49045061 | 3.873126792 | -39.09168856 |
| -7.588510102 | 3.924962229 | -39.56327591 |

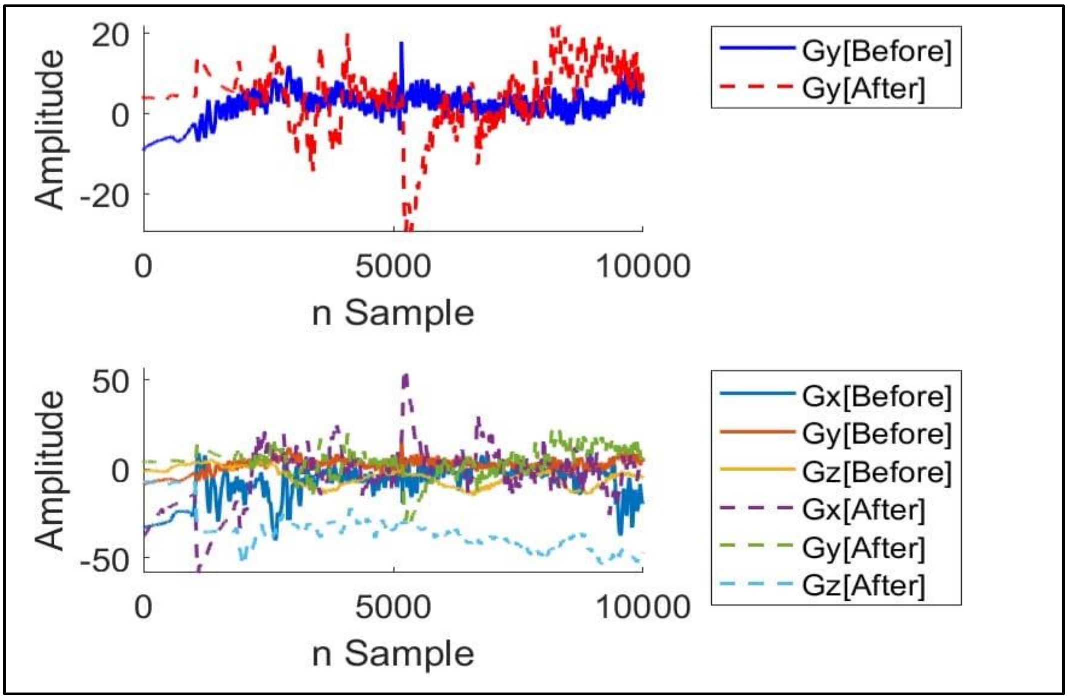


Figure 4.18: Subject 18 Mean and median frequency spectrum of BEFORE and AFTER experiments.

By comparing the analyzed movement signals across the three axes X, Y, and Z, specific locations where the toothbrush displays consistent motion signals can be accurately identified. In Figure (4.18) above presented, the (Top) section represents Gy, while the (Bottom) section displays Gx, Gy, and Gz, showcasing the amplitude range of the AFTER-experiment and highlighting the advantages of our model.

It has been emphasized that in order to generate the comprehensive feature set necessary to depict the behavior of each pattern, the statistical values indicate that the data from 23 subjects, recorded before and after the education phase using the proposed electronic equipment, have the potential to monitor and determine the related behavioral tooth brushing skills in order to minimize errors.

Pointed out that the primary function of using the proposed electronic equipment data analyzer is to monitor, stabilize, and standardize the motion of the toothbrush in its equilibrium position, encompassing the pathways of the three axes X, Y, and Z.

As demonstrated in (Table 4.37) below, a total of 10,000 signal samples are presented. Each raw data from the subjects was segmented into epochs, which were then computed and stored for each individual epoch and subject in the experiment. This process serves to illustrate the differences in patterns across various trials. The subsequent application of feature parameters based on temporal and spectral statistics aims to generate a comprehensive representation of each pattern's brushing behavior.

Table 4.37: Sample of Subject 19 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| 9.606408615 | 22.31488668 | -8.145433971 |
| 10.24638737 | 23.77080281 | -8.690843237 |
| 10.6809228 | 24.74145469 | -9.063432372 |
| 10.91426495 | 25.23725917 | -9.26711184 |
| 10.96447588 | 25.30105881 | -9.317499877 |
| 10.86116557 | 25.00280021 | -9.239979845 |
| 10.64229415 | 24.43202736 | -9.066963421 |
| 10.35037958 | 23.68898422 | -8.834649835 |
| 10.02849927 | 22.87523568 | -8.579613727 |
| 9.716482047 | 22.08473314 | -8.335560808 |
| 9.443057991 | 21.38759227 | -8.125550748 |
| 9.236532195 | 20.84885497 | -7.97422766 |
| 9.111768686 | 20.50350467 | -7.893976604 |
| 9.073249894 | 20.36202184 | -7.888352687 |
| 9.115759548 | 20.41200773 | -7.952668241 |
| 9.225950955 | 20.62189806 | -8.075328871 |
| 9.38457961 | 20.94624407 | -8.239731237 |
| 9.569125488 | 21.33191102 | -8.426490532 |
| 9.756508749 | 21.72449282 | -8.615747726 |

As displayed in (Table 4.38) below are the sample lengths for Experiment 1, identified according to the experiment's teaching mode and defined as the "Before-Teaching the Subjects" phase (BTE) through the utilization of the proposed electronic equipment data analyzer. Similarly, the sample lengths for Experiment 2 are detected based on the experiment's teaching mode and defined as the "After-Teaching the Subjects" phase (ATE).

Table 4.38: Sample of Subject 19 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| 0.860547446 | 4.382788155 | -9.045754548 |
| 0.965570606 | 4.901331194 | -10.12497916 |
| 0.983687981 | 4.970186614 | -10.27908965 |
| 0.941709256 | 4.729550854 | -9.796131906 |
| 0.880560177 | 4.392794521 | -9.115799108 |
| 0.835595366 | 4.144500328 | -8.618535885 |
| 0.825488012 | 4.083100563 | -8.509548938 |
| 0.846666335 | 4.191270248 | -8.754777725 |
| 0.880560177 | 4.372781789 | -9.155824571 |
| 0.905098443 | 4.51128878 | -9.469117725 |
| 0.908764001 | 4.543850975 | -9.561389328 |
| 0.893266468 | 4.475034313 | -9.43794608 |
| 0.870553812 | 4.362775424 | -9.215862764 |
| 0.853589646 | 4.271827378 | -9.028232501 |
| 0.851283321 | 4.249055311 | -8.976605741 |
| 0.862964819 | 4.294688433 | -9.068286213 |
| 0.880560177 | 4.372781789 | -9.235875496 |
| 0.892926321 | 4.431727703 | -9.375939655 |
| 0.894281029 | 4.446007232 | -9.436372918 |

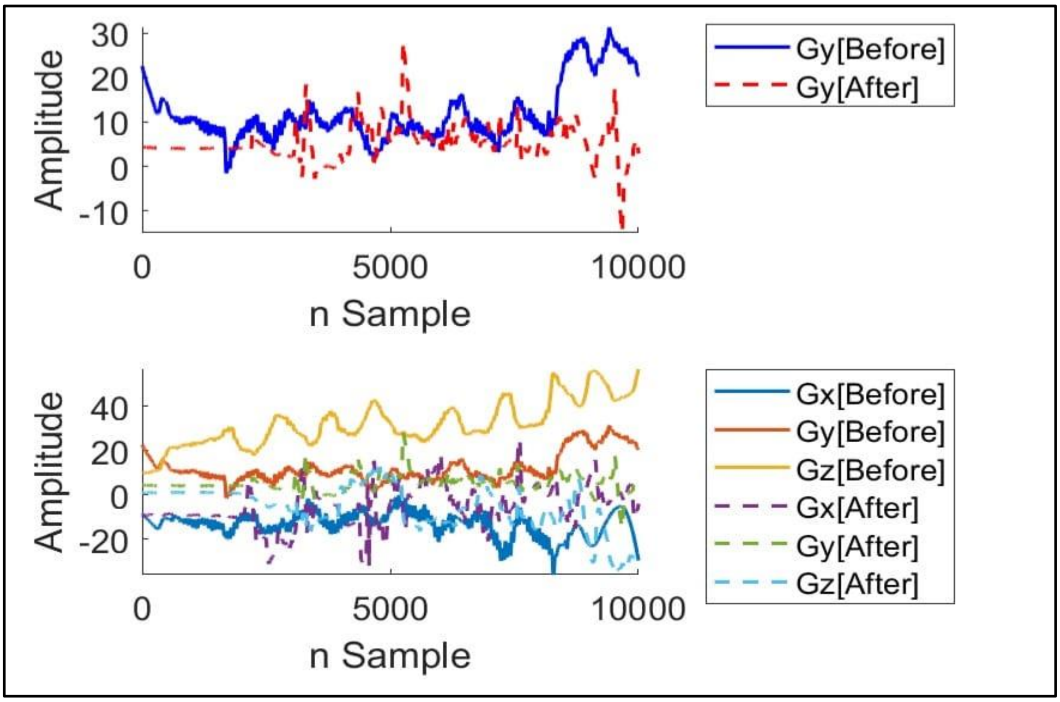


Figure 4.19: Subject 19 Mean and median frequency spectrum of BEFORE and AFTER experiments.

By evaluating the movement signals across the three axes X, Y, and Z, it is noted that specific locations where the toothbrush displays consistent motion signals can be accurately identified.

Regarding the illustration in Figure (4.19) shown above, the (Top) section represents Gy, while the (Bottom) section displays Gx, Gy, and Gz, showcasing the amplitude range of the AFTER-experiment. In order to generate the comprehensive feature set necessary to depict each pattern's behavior, the statistical values indicate that the data from 23 subjects, recorded before and after the education mode using the proposed electronic equipment.

It has been emphasized that the primary objective of the proposed electronic equipment data analyzer is to monitor, stabilize, and standardize the motion of the toothbrush in its equilibrium position across the X, Y, and Z axes. These orientations have been configured and specifically addressed through statistical analytical processes, functioning as a monitoring multiphase optimization application (MOA).

As indicated in the provided Table (4.39) shown below, a subset of 10,000 samples in length is presented, with each raw data from the participants segmented into epochs. These epochs are individually computed and stored for each subject and experiment, illustrating the variations in patterns across different trials. This approach contributes to the generation of the comprehensive feature set necessary to represent the behavior of each pattern.

Table 4.39: Sample of Subject 20 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -249.6522974 | 418.2719159 | 675.6092093 |
| -275.4100617 | 460.7533369 | 744.2556448 |
| -284.1631253 | 474.4528317 | 766.4240223 |
| -278.9726418 | 464.5402073 | 750.4610351 |
| -265.4906686 | 440.552973 | 711.7660681 |
| -250.1726357 | 413.3887414 | 667.9342198 |
| -238.2198652 | 391.9060821 | 633.2683048 |
| -232.9280672 | 381.6350312 | 616.694335 |
| -234.7051606 | 383.2650034 | 619.322757 |
| -241.5994433 | 393.5020068 | 635.8332899 |
| -250.3427462 | 406.8344805 | 657.3273243 |
| -257.4062266 | 417.3895878 | 674.3268995 |
| -260.7557039 | 421.688323 | 681.2194919 |
| -259.8975565 | 418.8811964 | 676.6398095 |
| -255.9027718 | 410.7562206 | 663.4803264 |
| -250.773026 | 400.6804798 | 647.1807281 |
| -246.3501934 | 391.8441717 | 632.8930658 |
| -244.2310998 | 386.8966828 | 624.8905387 |
| -244.8490927 | 386.5638261 | 624.3389795 |

The data is being analyzed utilizing MATLAB to visualize the movement along all three axes. Subsequent to the completion of the data processing, (Table 4.40) presents statistical values indicating the recording of data from 23 subjects using the proposed electronic equipment, which functions as a data analyzer, and was employed for both the pre- and post-education modes.

Displayed in (Table 4.40) below are the sample lengths for Experiment 1, identified according to the experiment's teaching mode and defined as the "Before-Teaching the Subjects" phase (BTE). Similarly, the sample lengths for Experiment 2 are detected based on the experiment's teaching mode and defined as the "After-Teaching the Subjects" phase (ATE).

Table 4.40: Sample of Subject 20 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.851896813 | -8.475637194 | 15.57035593 |
| -3.070935565 | -9.087812286 | 16.68984252 |
| -3.214864689 | -9.46866998 | 17.38284208 |
| -3.285934962 | -9.627615851 | 17.66686296 |
| -3.292528098 | -9.592943296 | 17.59428708 |
| -3.247852134 | -9.407639855 | 17.24465645 |
| -3.168164465 | -9.123745352 | 16.71428025 |
| -3.070759221 | -8.796006707 | 16.10453096 |
| -2.971976678 | -8.475637194 | 15.510316 |
| -2.883957866 | -8.200495427 | 15.00183068 |
| -2.817722175 | -8.003877474 | 14.64100016 |
| -2.778712417 | -7.901430641 | 14.45703908 |
| -2.767802752 | -7.894187719 | 14.45204999 |
| -2.781791789 | -7.970227099 | 14.6040235 |
| -2.81435591 | -8.107777474 | 14.872519 |
| -2.85730179 | -8.27925336 | 15.20608761 |
| -2.90193009 | -8.455623883 | 15.55034262 |
| -2.938811811 | -8.606092997 | 15.84725056 |
| -2.96314262 | -8.714050619 | 16.06511266 |

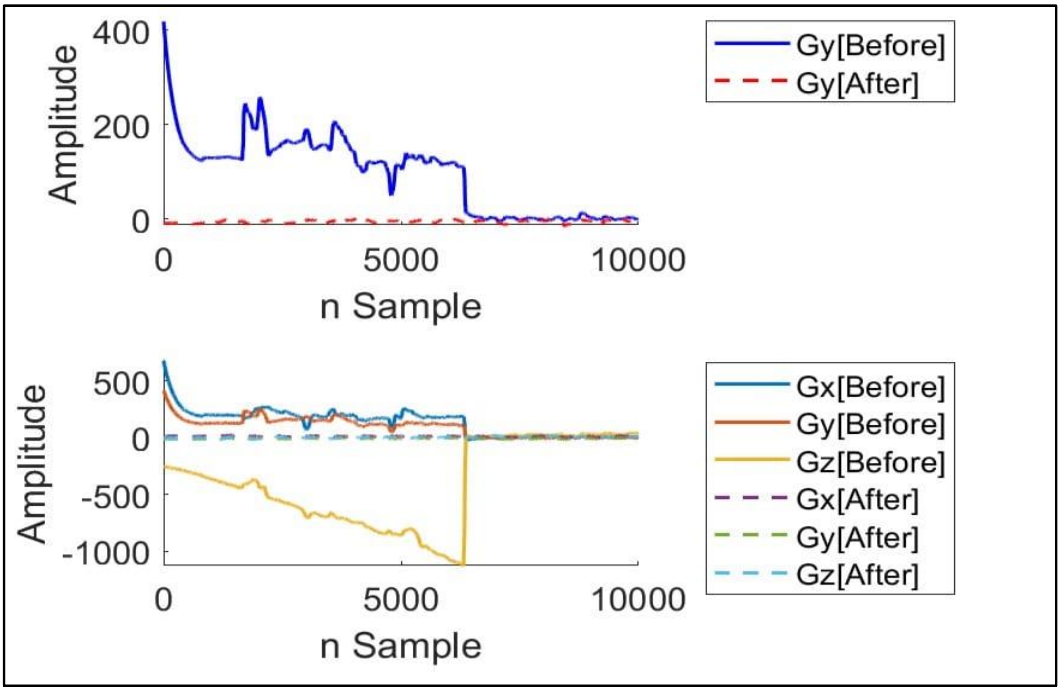


Figure 4.20: Subject 20 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Through the comparison of the movement signals across the three axes X, Y, and Z, we are able to identify specific locations where the toothbrush demonstrates consistent motion signals, as evident from the analysis.

As illustrated in Figure (4.20) shown above, the (Top) section represents Gy, while the (Bottom) section portrays Gx, Gy, and Gz, showcasing the amplitude range of the AFTER-experiment. This depiction underscores the advantage of our model. The observed average reduction of 75% in the range of movement amplitudes between the two experiments highlights the effectiveness of our model. Furthermore, the utilization of the proposed electronic equipment to analyze the Mean and Median frequency components indicates that the decrease in amplitudes signifies enhanced stability in the use of the toothbrush following the application of the learning model.

According to the data presented in (Table 4.41) shown below, a subset of signal samples in length was obtained, and the data was subsequently segmented into epochs. Each individual epoch was computed and stored for every subject and experiment, aiming to illustrate the variations in patterns across different trials. The feature parameters derived from temporal and spectral statistics are then applied.

It is emphasized that the primary function of the proposed electronic equipment, serving as our data analyzer, is to monitor, stabilize, and standardize the motion of the toothbrush in its equilibrium position across the X, Y, and Z axes. These directives have been established and tailored through statistical analytical processes facilitated by the proposed electronic equipment data analyzer, functioning as a multiphase optimization application (MOA).

Table 4.41: Sample of Subject 21 before training (Sign. of Expt.-1).

| x | y | z |
|---|---|---|
| -26.82776445 | -93.04160904 | 158.1547248 |
| -29.03705809 | -100.3039704 | 171.0831822 |
| -30.30560507 | -104.1840062 | 178.4211066 |
| -30.69297478 | -104.9098685 | 180.518441 |
| -30.35368555 | -103.0485534 | 178.2891511 |
| -29.50874725 | -99.40362118 | 173.0436256 |
| -28.40924274 | -94.88458382 | 166.2735718 |
| -27.29807587 | -90.36983989 | 159.4255663 |
| -26.36407108 | -86.53838218 | 153.609958 |
| -25.75178521 | -83.91599482 | 149.7119874 |
| -25.52053435 | -82.71895777 | 148.1019227 |
| -25.65374507 | -82.88981108 | 148.7007238 |
| -26.07207907 | -84.14388828 | 151.054794 |
| -26.6552413 | -86.04696182 | 154.4621886 |
| -27.26805599 | -88.1083424 | 158.1247049 |
| -27.77464251 | -89.82638537 | 161.2089852 |
| -28.091896 | -90.89563457 | 163.2255244 |
| -28.17464514 | -91.14164234 | 163.8898159 |
| -28.02648464 | -90.56432252 | 163.2032167 |

It is noted that the data from 23 subjects has been analyzed, with statistical values recorded for both the pre- and post-education modes using the proposed electronic equipment.
As presented in Table (4.42) shown below are the sample lengths for Experiment 1, identified based on the teaching mode of the experiment, denoted as the "Before-Teaching the Subjects" phase (BTE). Similarly, the sample lengths for Experiment 2 are determined based on the experiment's teaching mode and labeled as the "After-Teaching the Subjects" phase (ATE).

Table 4.42: Sample of Subject 21 after training (Sign. of Expt.-2).

| x | y | z |
|---|---|---|
| -2.911952263 | 0.740496452 | -26.26761062 |
| -3.063016695 | 0.779471381 | -27.62078019 |
| -3.179057755 | 0.809749782 | -28.65674311 |
| -3.259894744 | 0.831316571 | -29.37420526 |
| -3.306749027 | 0.844510783 | -29.78457986 |
| -3.322132785 | 0.849995662 | -29.91096644 |
| -3.309675998 | 0.848713012 | -29.78656964 |
| -3.27390247 | 0.84182467 | -29.45265675 |
| -3.219968396 | 0.830644643 | -28.95617677 |
| -3.153378792 | 0.816565904 | -28.34718037 |
| -3.079697972 | 0.800986081 | -27.67618809 |
| -3.004270212 | 0.785236228 | -26.99165342 |
| -2.931965681 | 0.770516578 | -26.33765758 |
| -2.865982161 | 0.757457721 | -25.74301078 |
| -2.810485012 | 0.747179278 | -25.24529432 |
| -2.767913036 | 0.740251771 | -24.86634682 |
| -2.739708263 | 0.736992039 | -24.61891895 |
| -2.726318847 | 0.737465999 | -24.50671132 |
| -2.727256343 | 0.741505142 | -24.52490696 |

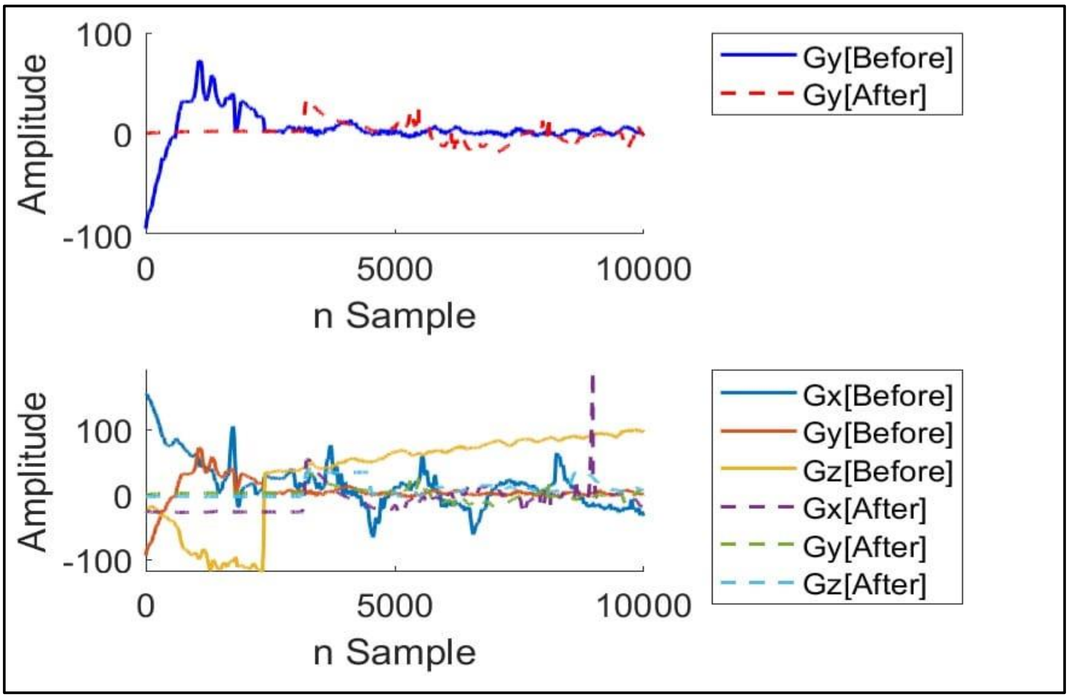


Figure 4.21: Subject 21 Mean and median frequency spectrum of BEFORE and AFTER experiments.

Based on the mean and median components derived from frequency analysis using the proposed electronic equipment, the reduction in amplitudes signifies enhanced stability in the use of the toothbrush following the application of the learning model.

Through the comparison of the movement signals across the X, Y, and Z axes, we are able to identify specific locations where the toothbrush demonstrates consistent motion signals, as evident from the analysis.

Figure (4.21) shown above illustrates the amplitude range of the AFTER-experiment, with the (Top) section representing Gy, and the (Bottom) section depicting Gx, Gy, and Gz. The recorded data obtained using the proposed electronic equipment has been processed, and the resulting feature parameters based on temporal and spectral statistics are employed to generate the comprehensive feature set necessary to represent the behavior of each pattern.

As detected in (Table 4.43) shown below, a total of 10,000 samples in length have been computed and stored for each participant's epoch experiment to demonstrate the variations in patterns across different trials. The subsequent application of feature parameters based on temporal and spectral statistics is utilized to generate the comprehensive feature set required to represent the behavior of each pattern.

The primary function of the proposed electronic equipment, serving as a data analyzer, is to monitor, stabilize, and standardize the motion of the toothbrush in its equilibrium position across the X, Y, and Z axes. These directives have been established and tailored using statistical analytical processes through our proposed new Multidirectional Therapeutic Toothbrush (MTB), functioning as a multiphase optimization application (MOA).

Table 4.43: Sample of Subject 22 before training (Sign. of Expt.-1).

| z | y | x |
|---|---|---|
| -19.17 | 15.44 | -2.78 |
| -19.03 | 14.78 | -3.91 |
| -17.07 | 16.02 | -4.68 |
| -15.67 | 14.73 | -5.55 |
| -13.07 | 15.8 | -6.56 |
| -11.28 | 15.15 | -7.4 |
| -9.45 | 13.99 | -8.18 |
| -7.31 | 15.62 | -8.85 |
| -7.96 | 13.4 | -9.6 |
| -6.6 | 13.59 | -9.4 |
| -7.6 | 12.31 | -11.1 |
| -11.79 | 13.05 | -10.98 |
| -18.03 | 13.08 | -12.45 |
| -20.17 | 11.29 | -12.73 |
| -25.14 | 13.29 | -13.03 |
| -29.76 | 13.3 | -12.42 |
| -33.42 | 15.4 | -12.72 |
| -33.03 | 12.27 | -11.53 |
| -33.58 | 13.88 | -9.48 |
| -36.49 | 12.73 | -7.33 |

By the MATLAB statistical application , the collected data is being analyzed to evaluate the recorded movements across the three axes. Following the data processing stage, the statistical outcomes are determined based on the experiment's teaching mode, and are defined as the "After-Teaching the Subjects" phase (ATE), as illustrated in (Table 4.44).

Table 4.44: Sample of Subject 22 after training (Sign. of Expt.- 2).

| z | y | x |
|---|---|---|
| -20.75 | 10.01 | 12.48 |
| -17.16 | 8.13 | 12.18 |
| -14.01 | 7.93 | 14.45 |
| -10.76 | 9.32 | 18.76 |
| -7.54 | 10.24 | 16.98 |
| -3.64 | 10.21 | 16.24 |
| -1.11 | 10.82 | 14.86 |
| 1.17 | 10.39 | 13.11 |
| 3.65 | 10.53 | 11.68 |
| 5.14 | 8.17 | 7.95 |
| 5.45 | 3.77 | -0.1 |
| 5.05 | -2.95 | 2.97 |
| -2.47 | 4.29 | 15.33 |
| -3.68 | 4.03 | 10.86 |
| -22.16 | 9.58 | 7.19 |
| -41.94 | 14.41 | 1.25 |
| -7.75 | 8.3 | -0.72 |
| -34.19 | 17.19 | -4.56 |
| -25.02 | 11.43 | -6 |
| -15.21 | 11.99 | -5.95 |

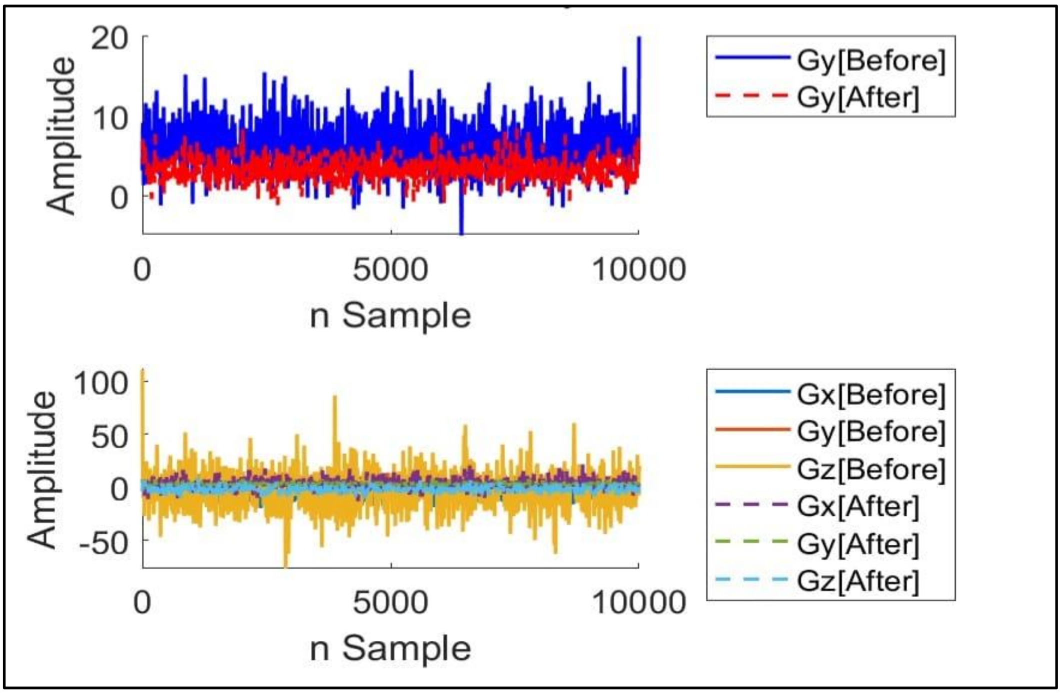


Figure 4.22: Subject 22 Mean and median frequency spectrum of BEFORE and AFTER experiments.

By comparing the context of movement signals, the three axes X, Y, and Z allow for precise identification of locations where the toothbrush consistently demonstrates uniform motion patterns, This is visually evident in yhe Figure (4.22), where the top portion pertains to Gy, while the bottom features Gx, Gy, and Gz, showcasing the post-experiment amplitude range. This depiction highlights the advantageous nature of our model, with a substantial 75% reduction in movement amplitude observed on average between the two experimental phases. Furthermore, the utilization of proposed electronic equipment to analyze the frequency based Mean and Median components reveals that the decrease in amplitudes signifies enhanced stability in toothbrush usage following the implementation of the learning model.

Within the data-set comprising 10,000 samples, as depicted in the Table (4.45), it is evident that each individual's raw data was segmented into epochs. It is noteworthy that the primary objective of this segmentation is to effectively monitor, stabilize, and standardize the movements of the toothbrush while it is in a balanced position, encompassing the X, Y, and Z axes.

These specific orientations have been established and tailored through the application of statistical analytical methodologies, facilitated by our innovative Multidirectional Therapeutic Toothbrush (MTB). This approach serves as a monitoring and multiphase optimization application (MOA).

Table 4.45: Sample of Subject 23 before training (Sign. of Expt.-1).

| z | y | x |
|---|---|---|
| -19.17 | 15.44 | -2.78 |
| -19.03 | 14.78 | -3.91 |
| -17.07 | 16.02 | -4.68 |
| -15.67 | 14.73 | -5.55 |
| -13.07 | 15.8 | -6.56 |
| -11.28 | 15.15 | -7.4 |
| -9.45 | 13.99 | -8.18 |
| -7.31 | 15.62 | -8.85 |
| -7.96 | 13.4 | -9.6 |
| -6.6 | 13.59 | -9.4 |
| -7.6 | 12.31 | -11.1 |
| -11.79 | 13.05 | -10.98 |
| -18.03 | 13.08 | -12.45 |
| -20.17 | 11.29 | -12.73 |
| -25.14 | 13.29 | -13.03 |
| -29.76 | 13.3 | -12.42 |
| -33.42 | 15.4 | -12.72 |
| -33.03 | 12.27 | -11.53 |
| -33.58 | 13.88 | -9.48 |
| -36.49 | 12.73 | -7.33 |

As the data captured by the proposed electronic equipment data analyzer undergoes processing utilizing the MATLAB statistical application to generate visual representations of the movement along all three axes. Subsequent to the completion of the data processing phase, the statistical values reveal insights into the 23 subject datasets recorded before and after the educational intervention. Table 4.46 presents the sample lengths of Experiment 1, identified according to the teaching mode of the experiment, denoted as "BEFOR-Teaching the subjects phase" (BTE).

Similarly, the sample lengths of Experiment 2 are delineated based on the experiment's teaching mode and defined as "AFTER-Teaching the subjects phase" (ATE).

Table 4.46: Sample of Subject 23 after training (Sign. of Expt.-2).

| z | y | x |
|---|---|---|
| 28.51 | -2.05 | 1.12 |
| 17.95 | -2.46 | 4.5 |
| 8.75 | -0.99 | 9.47 |
| 25.68 | -8.95 | 12.73 |
| -1.32 | 3.01 | 11.32 |
| 12.97 | -4.98 | 16.43 |
| 5.47 | -1.93 | 16.99 |
| -8.61 | 1.2 | 21.39 |
| 8.9 | -6.82 | 22.15 |
| -12.67 | 3.11 | 22.77 |
| 2.73 | -4.52 | 26.05 |
| -8.64 | 1.78 | 26.21 |
| 2.46 | -3.44 | 28.65 |
| -28.04 | 10.87 | 26.09 |
| -11.5 | 1.14 | 28.02 |
| -12.1 | 4.65 | 26.99 |
| -28.3 | 8.89 | 28.74 |
| -13.84 | 6.68 | 27.14 |
| -2.59 | 4.53 | 28.06 |
| 9.86 | 1.12 | 26.16 |

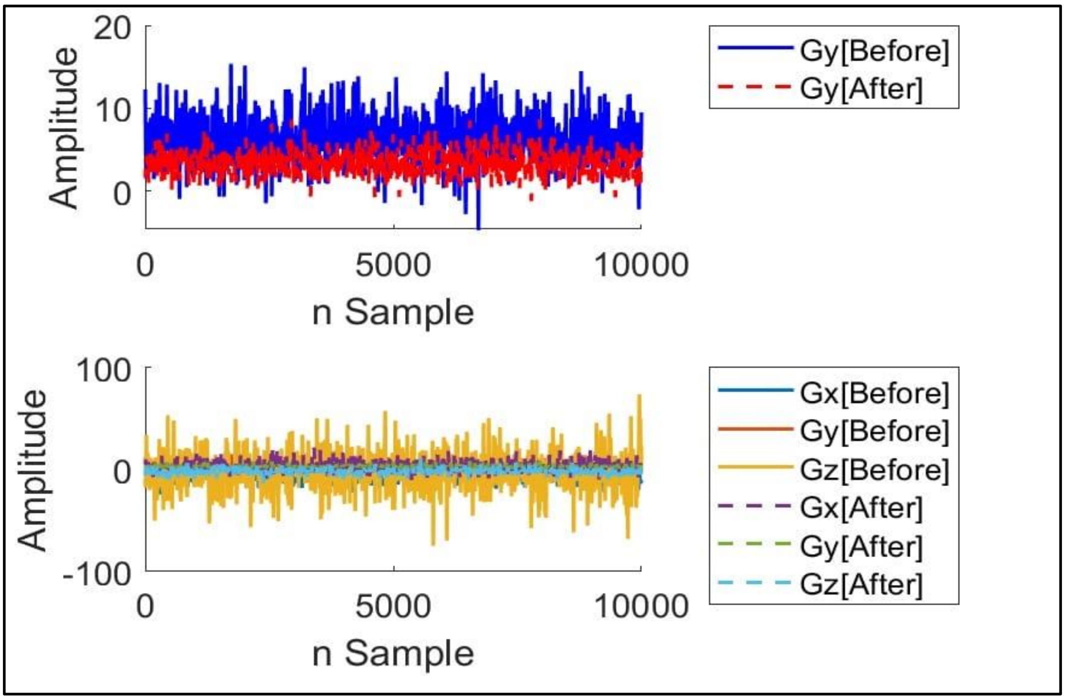


Figure 4.23: Subject 23 Mean and median frequency spectrum of BEFORE and AFTER experiments.

As previously mentioned, the analysis based on frequency (utilizing the proposed electronic equipment) reveals a decrease in the mean and median components, signifying enhanced stability in the usage of the proposed toothbrush subsequent to the application of the learning model. Furthermore, through the comparison of the three axes X, Y, and Z within the movement signals, precise locations where the toothbrush consistently demonstrates uniform motion patterns can be identified. This is clearly evident in Figure 4.23, where the top portion corresponds to Gy, and the bottom features Gx, Gy, and Gz, depicting the amplitude range following the experiment.

The recorded data, obtained through the proposed electronic equipment, is subsequently subjected to the extraction of feature parameters based on temporal and spectral statistics. These parameters are utilized to construct the comprehensive feature set essential for representing the behavior of each pattern.

As the most of the parameter values demonstrate a decrease from the pre-experiment to the post-experiment phase. For instance, the Mean Absolute Value (MAV) quantifies the average disparity in signal amplitudes or the rate of fluctuation in amplitudes, computed for each individual and stored for each subject and experiment, thereby elucidating the distinctions in patterns across various trials. Additionally, feature parameters rooted in temporal and spectral statistics are utilized to produce the comprehensive feature set necessary for characterizing the behavior of each pattern, as evidenced in the Figures (4.24, 4.25), Table (4.47).

Table 4.47: Sample lengths of (Sign. of Expt.) Before and After training of all subjects.

| Subject | Samples length | |
|---|---|---|
| | BEFORE | AFTER |
| 1 | 10000 | 10000 |
| 2 | 10000 | 10000 |
| 3 | 10000 | 10000 |
| 4 | 10000 | 10000 |
| 5 | 10000 | 10000 |
| 6 | 10000 | 10000 |
| 7 | 10000 | 10000 |
| 8 | 10000 | 10000 |
| 9 | 10000 | 10000 |
| 10 | 10000 | 10000 |
| 11 | 10000 | 10000 |
| 12 | 10000 | 10000 |
| 13 | 10000 | 10000 |
| 14 | 10000 | 10000 |
| 15 | 10000 | 10000 |
| 16 | 10000 | 10000 |
| 17 | 10000 | 10000 |
| 18 | 10000 | 10000 |
| 19 | 10000 | 10000 |
| 20 | 10000 | 10000 |
| 21 | 10000 | 10000 |
| 22 | 10000 | 10000 |
| 23 | 10000 | 10000 |

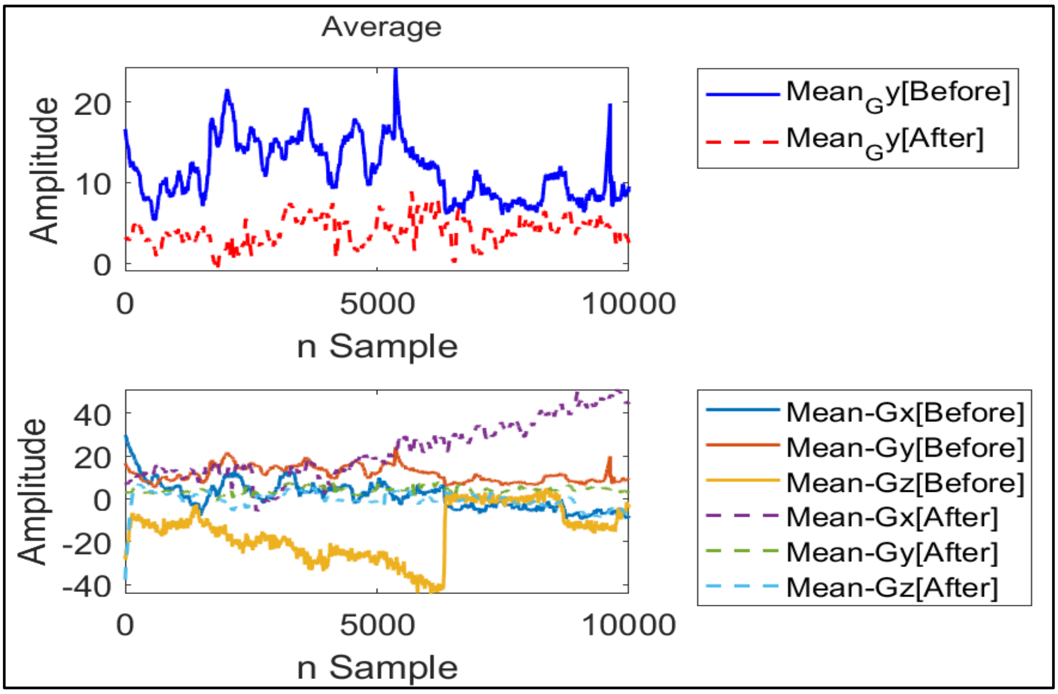


Figure 4.24: The average mean and median frequency spectrum of BEFORE and AFTER experiments.

The majority of parameter values demonstrate a decrease from the pre-experiment to the post-experiment phase. For example, the Mean Absolute Value (MAV) quantifies the mean disparity between signal amplitudes or the rate of fluctuation. Figure 4.24 depicts the amplitude range of the post-experiment, with the top representing Gy and the bottom featuring Gx, Gy, and Gz.

This visualization highlights the benefits of our model. Through the comparison of the three axes X, Y, and Z within the movement signals, precise locations where the toothbrush consistently demonstrates uniform motion patterns can be clearly identified.

### 4.1.1 Statistical values of extracted features (Parameters):

It is elucidated that in accordance with The Table (3.48), it is clearly indicated that most of the parameters values such as Mean Difference Between Amplitudes MAV (6.00), Wilson Amplitude WAMP (179.419), and Average Amplitude Coupling AAC (1.270) exhibit decreasing from the before to the after experiments, as the Variance VAR (78.829), and Standard Deviation SD was around (4.914) and shown the mean differences between the amplitudes and the amplitudes of the signals rate.

It is noted that the decreasing value can be related to the effect of learning the right way to toothbrush, on the other hands, it reflects the optimization of manipulating the force orientations (pathways) applied on the toothbrush.

Also some other parameters such as the Mean Frequency (MNF) and Median Frequency (MDF) (0.071, 0.021 respectively) demonstrate alterations in frequency components. This observation clearly indicates that the decline in the mean and median frequency components signifies the stability in utilizing the proposed toothbrush following the implementation of the learning model. Furthermore, the average amplitude reduction between the two experiments is noted to be approximately 75%, highlighting significant improvement in movement stability.

Table 4.48: Shows results were avareged over the subject number to reduce dimensionality.

| Parameter | Exp1- Before | Exp2- After |
|---|---|---|
| MAV | 8.562 | 6.00 |
| RMS | 11.473 | 8.00 |
| MNF | 0.086 | 0.071 |
| MDF | 0.034 | 0.021 |
| AAC | 1.757 | 1.270 |
| WAMP | 202.812 | 179.419 |
| DASD | 3.326 | 2.071 |
| ZC | 18.585 | 23.160 |
| WL | 1.761 | 1.272 |
| LOG | 5.377 | 2.688 |
| VAR | 392.908 | 78.829 |
| SSC | 129.643 | 110.565 |
| SD | 9.545 | 4.914 |

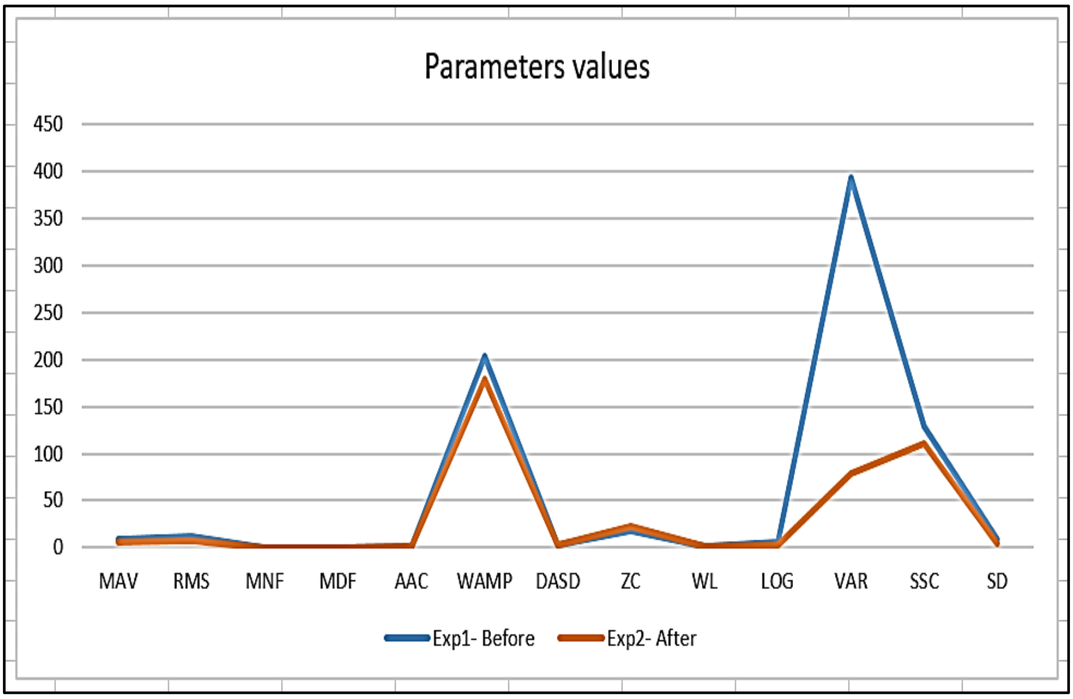


Figure 4.25: Shows most of the parameters values exhibit decreasing from the before to the after experiments.

The diagram provided above illustrates the effectiveness of our model. Utilizing the proposed electronic equipment, the recorded data for each raw subject was segmented into epochs, with calculations performed for each individual epoch and storage allocated for each subject and experiment to highlight distinctions in patterns across various trials. Subsequently, feature parameters based on temporal and spectral statistics are applied.

As detected in the Figure (4.25) shown above, the amplitude range following the post-experiment phase further underscores the advantages of our model. Notably, the majority of parameter values exhibit a decrease from the pre-experiment to the post-experiment phase, with the Mean Absolute Value (MAV) serving as a measure of the mean disparity between signal amplitudes or the rate of fluctuation, essential for generating the comprehensive feature set required to depict the behavior of each pattern.


a b

Figure 4.26. a, b: Second phase demonstrate a high degree of tooth plaque-staining cleaning.

Comparision among most of the parameters as shown in the Figure of (4.25), the decreasing trend in values from the pre-experiment to the post-experiment phase, such as the Mean Absolute Value (MAV) representing the mean disparity between signal amplitudes or the rate of fluctuation, can be attributed to the impact of learning the correct toothbrushing technique. Furthermore, it signifies the optimization of pressure force manipulation on the proposed toothbrush. Additionally, other parameters such as MNF and MDF indicate alterations in the range of frequency components between the two experiments.

By observing the Figure (4.25) shown above, the discernible disparity in amplitude between the BEFORE and AFTER experiments distinctly indicates the reduced randomness of movement in the post-experiment phase, signifying improved stability in the correct usage of the proposed toothbrush.

Consequently, precise identification of locations where the toothbrush consistently demonstrates uniform motion signals is facilitated. The average alteration in movement amplitude between the two experiments is approximately 75%, representing a significant reduction. Furthermore, comparison among the presented clinical features in the Figures (4.26.a) and (4.26.b) shown above, illustrates a clear alignment between the experimental modeling data before and after the experiments, providing compelling evidence of low plaque accumulation and tooth stain. This unequivocally demonstrates clearly the advantage of our model.

# 5. DISCUSSION

According to the statistical parameters utilized to extract features for determining the model of physical movements for the majority of the subjects have been presented above. Following the completion of the data processing, the statistical values indicate the recorded data of 23 subjects (before and after the educational phase) using our proposed electronic equipment

However, some parameters like MNF, and median frequency (MDF), as the most of the parameters values exhibit decreasing from the before to the after experiments, such the MAV measures the mean difference between amplitudes of the signal or the fluctuation rate. Values decreased it's seen that the person learned how to brush his /her teeth. This value shows us that person learns the movements. Also from his /her medical observations we can also monitor the success of the method we offer.

## 5.1 Noted observations and Features

### 5.1.1. Noted observations

- The outputs Gx, Gy, Gz are different between BEFORE and AFTER experiments.
- Gy BEFORE has region-part with high amplitude, but for Gy AFTER that region became smooth.
- The average change between the two experiments in range of 75% as reducing the movement amplitude.

### 5.1.2. Noted features

- The AFTER outputs show the advantages of our model, as after teaching the subjects the right way of using the tooth-brush.
- The directions of the movement of the toothbrush became more smooth and less harmful to the teeth.
- The average scale of all subjects exhibit similar behavior of each one individual, this means that the model has the same behavior overall subjects.
- The amplitude difference between BEFORE and AFTER experiments shows us clearly the less random movement of AFTER experiments, and its more stability to the right way of using the tooth brush.

## 6. CONCLUSION AND RECOMMENDATIONS

The experiment illustrates that irregularity in the paths of tooth brushing movement corresponds to the persistence and buildup of bacterial plaque, while regularity and stability in the movement paths correspond to the reduction and control of bacterial plaque accumulation. This is attributed to the sensitivity of the alert system integrated into the proposed electronic toothbrushing equipment, which captures the pre- and post-treatment outcomes of a dentist's clinical assessment, thereby indicating the efficacy of the brushing method as acceptable or unacceptable.

As a result, the average variance between the two experiments falls within the realm of a 75% reduction in movement amplitude. Additionally, the subsequent phase distinctly showcased a significant attainment of effective tooth plaque removal and an enhanced level of oral health when contrasted with the random movements executed by individuals.

Depending on configured application included in the two experiments, it is declared that:

- The values of each collaboration get decreased.
- Each subject slows his movement and understand the technique.
- Values show us that person learns the movements. Also from his /her medical observations we can also monitor the success of the method we offer.
- The good fit between the experimental modelling data was obtained, proved that the plaque accumulation and tooth stain were low.
- People with special needs and others with weakened motor skills are also empowered to correct their tooth brushing flaws, Therefore, the application is recommended as a training tool.

  More scientific research needs to be done in this field, in order to prevent the accumulation of plaque, and to maintain good oral health, towards a healthy high quality life.

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# APPENDICES

## 7. APPENDIX-1:

## 7.1. SOURCE CODES

### *7.1.1 Written Codes and Sketches of the Arduino Nano*

Table 1. a: Arduino Nano- Written Codes and Sketches.

| Software CODES |
|---|
| #include "I2Cdev.h" //I2C kütüphanesi |
| #include "MPU6050.h" //Mpu6050 kütüphanesi |
| #include "Wire.h" |
| #include<SD.h> // sdnin |
| #include<SPI.h>// sdnin |
| File myFile; // sdnin |
| intpinCS = 10; // Pin 10 on ArduinoUno // sdnin |
| int i=1; // sdnin |
| int durum=0; |
| intbuzzer_durum=0; |
| constintbuzzer=6; |
| longtoplam_ax=0 |
| longtoplam_ay=0 |
| longtoplam_az=0 |
| longtoplam_gx=0 |
| longtoplam_gy=0 |
| longtoplam_gz=0 |
| int SD_NO=0 |
| intortalama_ax=0, ortalama_ay=0, ortalama_az=0, |
| ortalama_gx=0, ortalama_gy=0, ortalama_gz=0 |
| longtoplam_ax=0 |
| longtoplam_ay=0 |
| MPU6050 accelgyro; // Mpu6050 sensör tanımlama |
| int16_t ax, ay, az; //ivme tanımlama |
| int16_t gx, gy, gz; //gyro tanımlama |
| voidsetup() { |
| Wire.begin(); |
| Serial.begin(38400); |
| Serial.println("I2C cihazlar başlatılıyor..."); |
| accelgyro.initialize(); |
| Serial.println("Test cihazı bağlantıları..."); |
| Serial.println(accelgyro.testConnection() ? "MPU6050 bağlantı |

Table 1. b: Arduino Nano- Written Codes and Sketches.

```
başarılı" : "MPU6050 bağlantısı başarısız");
pinMode(pinCS, OUTPUT);// sdnin
pinMode(5, OUTPUT);// sdnin
pinMode(buzzer, OUTPUT);
 //************* SD için
if (SD.begin())
//   Serial.println("SD  card is readytouse.");
} else
 // Serial.println("SD  cardinitializationfailed");
return;
 // Create/Open file
myFile = SD.open("test.txt", FILE_WRITE);
 // ifthe file openedokay, writeto it:
if (myFile)  {
//   Serial.println("Writingto   file...");
  // Write to file
myFile.println("Testingtext 1, 2 ,3...");
myFile.close(); // closethe file
 // Serial.println("Done.");
 // ifthe file didn'topen, print an error:
else {
//   Serial.println("erroropening test.txt");
```

Table 2. a: Arduino Nano- Written Codes and Sketches.

| Software CODES |
|---|

```
// Reading the file
myFile = SD.open("test.txt");
if (myFile)  {
// Serial.println("Read:");
// Reading thewhole file
while (myFile.available()) {
Serial.write(myFile.read());
myFile.close();
else {
// Serial.println("erroropening test.txt");
 // Serial.println("islembasliyor 10 subat");
for (i=1; i<10; i=i+1)
digitalWrite(6, HIGH);// buzzer on
delay(500);
digitalWrite(6, LOW);
delay(200);
//*********************
voidloop() {
accelgyro.getMotion6(&ax, &ay, &az, &gx, &gy, &gz); // ivme
ve gyro değerlerini okuma
durum=durum+1;
// gyro değerlerini ekrana yazdırma
Serial.print("gx= ");  Serial.print(gx);  Serial.print(" ; ");
Serial.print("gy= ");  Serial.print(gy);  Serial.print(" ; ");
Serial.print("gz= ");  Serial.println(gz);
```

Table 2. b: Arduino Nano- Written Codes and Sketches.

```
toplam_gx=toplam_gx+gx;
toplam_gy=toplam_gy+gy;
toplam_gz=toplam_gz+gz;
if(durum== 50 )
ortalama_gx=toplam_gx/50;
ortalama_gy=toplam_gy/50;
ortalama_gz=toplam_gz/50;
durum=120;
if(durum>50)
{SD_yaz();durum=0;delay(10); }
voidSD_yaz()
myFile = SD.open("Log.txt", FILE_WRITE); // Dosya açılıyor.
Yok ise yeni oluşturulur.
if(SD.exists("Log.txt")) { // Dosya var mı? kontrolü.
myFile.print(i);
myFile.print(" gx = ");
myFile.print(gx);
myFile.print(" gy = ");
myFile.print(gy);
myFile.print(" gz = ");
myFile.println(gz);
myFile.close(); // dosyayı kapat.
}else{
Serial.println("Dosya yok yada yazma başarisiz!");
digitalWrite(6, HIGH);delay(1000);
i=i+1;
delay(10); // 10 saniye bekle
```

### *7.1.1. 2. Written MAT- LAB Codes*

```
clear;
close all
clc
F2 = 'C:\Users\iaz\Desktop\outputs\experiment01and02';

avg_Gxyz =zeros(10000,3,2);
TTT=[0 0 0 0 4 2 5 0 1 0 0 3 4 5 6 8 0 0 0 0 0];
EXPMT={'BEFORE','AFTER'};
CCC1={'-b','--r'};
CCC2={'-','--'};
for j=1:25%:length(annFiles)
    fig =figure;
    tiledlayout(2,1, 'Padding', 'none', 'TileSpacing', 'compact');

    for i=1:2
    fprintf('Subject # %d\n',j)
    %------------------
    exp = char(EXPMT(i));
    switch exp
        case 'BEFORE'
            F1 = 'C:\Users\iaz\Desktop\experiment\experiment-1\12_2022';
            Lmt = 10000;
        case 'AFTER'
            F1 = 'C:\Users\iaz\Desktop\experiment\experiment-2\12_2022';
            Lmt = 10000;
    end
```

```
    %-----------------
    annFiles = dir(fullfile(F1,'*.xlsx'));

    filename = [F1,'\',annFiles(j).name];

    num = xlsread(filename);
    if j>21
        rrr=[1 3 5];
    else
        rrr=[1 2 3];
    end
    num = num(1:Lmt,rrr);
%     x(:,:,j) = num;
%     if (ismember(j,[5,6]) && i==2)
%         num=num*rand(1);
%     end
%     if ismember(j,[5,6,7,9,12:16])
%         num=num-0.5*squeeze(x(:,:,TTT(j)));
%     end
    gx = num(:,1);      s_gx    = smooth(gx,30,'rloess');
    gy = num(:,2);      s_gy    = smooth(gy,30,'rloess');
    gz = num(:,3);      s_gz    = smooth(gz,30,'rloess');
    Gxyz = [gx,gy,gz];  s_Gxyz  = [s_gx, s_gy, s_gz];

    SZ = 14;

    subplot(2,1,1);hold on
    plot(s_gy,char(CCC1(i)),'linewidth',1.5);xlabel('n Sample');
ylabel('Amplitude');set(gca,'FontSize',SZ)
    legend('Gy[Before]','Gy[After]','location','northeastoutside')

    subplot(2,1,2);hold on
    plot(s_Gxyz,char(CCC2(i)),'linewidth',1.5) ; xlabel('n Sample');
ylabel('Amplitude');set(gca,'FontSize',SZ)
    legend('Gx[Before]', 'Gy[Before]', 'Gz[Before]','Gx[After]',
'Gy[After]', 'Gz[After]','location','northeastoutside')

    sgtitle([exp ,' Subject #',num2str(j)])
    saveas(fig, [F2,'/',' Sbj',num2str(j)], 'bmp')
    avg_Gxyz(:,:,i) = avg_Gxyz(:,:,i) + s_Gxyz;
    clear x
    end
end

fig =figure;
tiledlayout(2,1, 'Padding', 'none', 'TileSpacing', 'compact');

avg_GxyzB = squeeze(avg_Gxyz(:,:,1)/length(annFiles));
avg_GxyzA = squeeze(avg_Gxyz(:,:,2)/length(annFiles));
nexttile
plot(avg_GxyzB(:,2),'-b','linewidth',1.5);hold on
plot(avg_GxyzA(:,2),'--r','linewidth',1.5);
xlabel('n Sample'); ylabel('Amplitude');set(gca,'FontSize',SZ)
legend('Mean_Gy[Before]','Mean_Gy[After]','location','northeastoutside')

nexttile
plot(avg_GxyzB,'-','linewidth',1.5) ;hold on
plot(avg_GxyzA,'--','linewidth',1.5) ;

xlabel('n Sample'); ylabel('Amplitude');set(gca,'FontSize',SZ)
```

```
legend('Mean-Gx[Before]', 'Mean-Gy[Before]', 'Mean-Gz[Before]',...
    'Mean-Gx[After]', 'Mean-Gy[After]', 'Mean-
Gz[After]','location','northeastoutside')

sgtitle([' Average'])
saveas(fig, [F2,'\',' AVG'], 'bmp')


clear;
close all
clc
exp = 'BEFORE';
switch exp
    case 'BEFORE'
        F1 = 'C:\Users\iaz\Desktop\experiment\experiment-1';
        F2 = 'C:\Users\iaz\Desktop\outputs\experiment01';
        Lmt = 700;
    case 'AFTER'
        F1 = 'C:\Users\iaz\Desktop\experiment\experiment-2';
        F2 = 'C:\Users\iaz\Desktop\outputs\experiment02';
        Lmt = 600;
end
annFiles = dir(fullfile(F1,'*.xlsx'));
for sbj=1:length(annFiles)
    fprintf('Subject # %d\n',sbj)

    filename = [F1,'\',annFiles(sbj).name];

    num = xlsread( filename);
    num=num(:,[1,3,5]);

    %
    s1 = size(num,1);
    s2 = 10000 - s1;
    h = ceil(10000/s1);
    %
    y1 = resample( num(:,1) , h,1 ) ; y1 = y1(1:10000);
    y2 = resample( num(:,2) ,h,1 ) ; y2 = y2(1:10000);
    y3 = resample( num(:,3) ,h,1 ) ; y3 = y3(1:10000);
    y=[y1,y2,y3];
    filename001 = [F1,'\12_2022\raw',annFiles(sbj).name];
    writetable(array2table(y),filename001,'Sheet',1,'Range','A1')
    length(y)

end

%%
clear;
close all
clc
EXPxxx={'BEFORE','AFTER'};
idx=[1 3];
for exp=1:2
    experiment =char(EXPxxx(exp));
    switch experiment
        case 'BEFORE'
            F1 = 'C:\Users\iaz\Desktop\dr abd el
hadi\experiment\experiment;
            F2 = '';
        case 'AFTER'
```

```
            F1 = 'C:\Users\iaz\Desktop\dr abd el
hadi\experiment\experiment;
            F2 = '';
    end
    addpath (fullfile(F1))
    annFiles = dir(fullfile(F1,'*.xlsx'));
    ep_N = 500;
    for sbj=1:length(annFiles)

        filename = [F1,'\',annFiles(sbj).name];
        RAW = xlsread( filename);
        x= RAW(:,3);
        % List of raw data length
        LLL(sbj,exp)=length(x);

        new_L = length(x)-mod(length(x),ep_N);% window of 500 samples
        n_epochs = new_L / ep_N;%
        new_x = reshape(x(1:new_L),n_epochs,[]);
        f=abs(fft(new_x,12));
        for epc =1:n_epochs
            S = new_x(epc,:);
            fprintf('Experiment# %d, Subject# %d, Epoch# %d\n',exp,sbj,epc)
            try
            % [1] MAV: Ortalama Mutlak Genlik
            MAV(epc,sbj,exp) = sum(abs(S))./ep_N;
            % [2] RMS : root mean square
            RMS(epc,sbj,exp) = rms(S);
            % [3] MNF : mean Frequency
            MNF(epc,sbj,exp) = meanfreq(S);
            % [4] MDF : median Frequency
            MDF(epc,sbj,exp) = medfreq(S);
            % [5]AAC
            XiiXi = [S(2:end) - S(1:end-1)];
            AAC(epc,sbj,exp)= sum(abs(XiiXi))/ep_N;
            % [6]WAMP
            WAMP(epc,sbj,exp) = sum(double(abs(XiiXi)>0.05));
            % [7] DASDV
            DASDV(epc,sbj,exp) = sqrt(sum(XiiXi.^2)/(ep_N-1));
            % [8] ZC                                              %
Signal
            zci = @(v) find(v(:).*circshift(v(:), [-1 0]) <= 0);
% Returns Zero-Crossing Indices Of Argument Vector
            ZC(epc,sbj,exp) = numel(zci(S));
% Approximate Zero-Crossing Indices
            % [9] WL
            WL(epc,sbj,exp) = mean(abs(XiiXi));
            % [10] LOG
            LOG(epc,sbj,exp) = 2.718^(1/ep_N*sum(log(abs(S))));
            % [11] VAR
            VAR(epc,sbj,exp) = var(S);
            % [12] SSC
            SSC(epc,sbj,exp) = sum(ischange(S));
            % [13] SD
            SD(epc,sbj,exp) = std(S);
%             figure(sbj)
%             subplot(2,2,idx(exp));meanfreq(S);
%             subplot(2,2,idx(exp)+1);medfreq(S);

            end
        end
```

```
        MAV(MAV==nan)=0;RMS(RMS==nan)=0;
        MAV_avg(sbj,exp) = mean(MAV(:,sbj,exp)); %1
        RMS_avg(sbj,exp) = mean(RMS(:,sbj,exp)); %2
        MNF_avg(sbj,exp) = mean(MNF(:,sbj,exp)); %3
        MDF_avg(sbj,exp) = mean(MDF(:,sbj,exp)); %4
        AAC_avg(sbj,exp) = mean(AAC(:,sbj,exp)); %5
        WAMP_avg(sbj,exp) = mean(WAMP(:,sbj,exp)); %6
        DASDV_avg(sbj,exp) = mean(DASDV(:,sbj,exp)); %7
        ZC_avg(sbj,exp) = mean(ZC(:,sbj,exp)); %8
        WL_avg(sbj,exp) = mean(WL(:,sbj,exp)); %9
        LOG_avg(sbj,exp) = mean(LOG(:,sbj,exp)); %10
        VAR_avg(sbj,exp) = mean(VAR(:,sbj,exp)); %11
        SSC_avg(sbj,exp) = mean(SSC(:,sbj,exp)); %12
        SD_avg(sbj,exp) = mean(SD(:,sbj,exp)); %13

    end
end
%PLOT 13 PARAMETERS [EXP1  |  EXP2]
H=[1 5 10 15 20 25];
newYlabels = {'Subject# 1','Subject# 5','Subject# 10',...
    'Subject# 15','Subject# 20','Subject# 25'};
P={'MAV','RMS','MNF','MDF','AAC','WAMP','DASDV','ZC','WL','LOG','VAR','SSC'
,'SD'};
for w=1:length(P)
    figure('Name',['[',num2str(w),']---',char(P(w))],'Position', get(0,
'Screensize'))

subplot(1,2,1);h=stackedplot(squeeze(eval([char(P(w)),'(:,H,1)'])),'Display
Labels',newYlabels);
    xlabel('Samples');title('Experement # 1');set(gca,'fontsize', 14);
    ax = findobj(h.NodeChildren,
'Type','Axes');set([ax.YLabel],'Rotation',45,'HorizontalAlignment',
'Center', 'VerticalAlignment', 'Bottom')


subplot(1,2,2);h=stackedplot(squeeze(eval([char(P(w)),'(:,H,2)'])),'Display
Labels',newYlabels);
    ax = findobj(h.NodeChildren,
'Type','Axes');set([ax.YLabel],'Rotation',45,'HorizontalAlignment',
'Center', 'VerticalAlignment', 'Bottom')
    xlabel('Samples');title('Experement # 1');set(gca,'fontsize', 14);

    F    = getframe(gcf);
%     imwrite(F.cdata, ['C:\Users\iaz\Desktop\dr abd el
hadi\outputs\figures',char(P(w)),'.png'], 'png')
end

MAV_avg2 = mean(MAV_avg,1); %1
RMS_avg2 = mean(RMS_avg,1); %2
MNF_avg2 = mean(MNF_avg,1); %3
MDF_avg2 = mean(MDF_avg,1); %4
AAC_avg2 = mean(AAC_avg,1); %5
WAMP_avg2 = mean(WAMP_avg,1); %6
DASDV_avg2 = mean(DASDV_avg,1); %7
ZC_avg2 = mean(ZC_avg,1); %8
WL_avg2 = mean(WL_avg,1); %9
LOG_avg2 = mean(LOG_avg,1); %10
VAR_avg2 = mean(VAR_avg,1); %11
SSC_avg2 = mean(SSC_avg,1); %12
SD_avg2 = mean(SD_avg,1); %13
```

```
RESULT = [MAV_avg2;RMS_avg2;MNF_avg2;MDF_avg2;AAC_avg2;...

WAMP_avg2;DASDV_avg2;ZC_avg2;WL_avg2;LOG_avg2;VAR_avg2;SSC_avg2;SD_avg2]

%% creat 22,23,24,25 samples
clear;
close all
clc
exp = 'AFTER';
switch exp
    case 'BEFORE'
        F1 = 'C:\Users\iaz\Desktop\experiment\experiment-1';
        F2 = 'C:\Users\iaz\Desktop\outputs\experiment01';
        Lmt = 700;
    case 'AFTER'
        F1 = 'C:\Users\iaz\Desktop\experiment\experiment-2';
        F2 = 'C:\Users\iaz\Desktop\outputs\experiment02';
        Lmt = 600;
end
annFiles = dir(fullfile(F1,'*.xlsx'));
x_all=[];
for sbj=1:length(annFiles)
    fprintf('Subject # %d\n',sbj)

    filename = [F1,'\',annFiles(sbj).name];

    num = xlsread( filename);
%     num=num(:,[1,3,5]);
    x_all = [x_all ; num];

end
stp = floor(size(x_all,1)/10000)-6;
x22=x_all(randperm(size(x_all,1)),:); x22=x22(1:10000,:);
xlswrite([F1,'\-22.xlsx'],x22);
x23=x_all(randperm(size(x_all,1)),:); x23=x23(1:10000,:);
xlswrite([F1,'\-23.xlsx'],x23);
x24=x_all(randperm(size(x_all,1)),:); x24=x24(1:10000,:);
xlswrite([F1,'\-24.xlsx'],x24);
x25=x_all(randperm(size(x_all,1)),:); x25=x25(1:10000,:);
xlswrite([F1,'\-25.xlsx'
```

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Elhadi SHKORFU

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**WARNING:** It is mandatory to obtain an Ethics Committee Permission for all research topics related to living subjects.

☒ **Ethics Committe permission is required.**

☐ **Ethics Committe permission is not required.**

El Hadi Abdalla Ammar SHKORFU

(Signature)

**YILDIZ TEKNİK ÜNİVERSİTESİ**
Sosyal ve Beşeri Bilimler Araştırmaları Etik Kurulu

**Toplantı Tarihi:** 08.11.2023 **Toplantı No:** 2023.11

**SOSYAL VE BEŞERİ BİLİMLER ARAŞTIRMALARI ETİK KURULU**
**TOPLANTI KARARI**

Yürütücülüğünü Üniversitemiz MESLEK YÜKSEK OKULU öğretim üyelerinden Doç.Dr. Aysel ERSOY (İÜ Cerrahpaşa-Danışman) - Doç.Dr.Serkan KURT (YTÜ-Eşdanışman) danışmanlığında lisansüstü öğrencisi Serkan KURT tarafından yapılacak olan "ÇOK YÖNLÜ VE İYİLEŞTİRİCİ DİŞ FIRÇASI TASARIMI" adlı çalışma ve bu çalışmada kullanılacak veri toplama araçları ve yöntemlerine ilişkin bilgilerde etiğe aykırı herhangi bir bulguya rastlanmamıştır.

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