Grip Force Response to Oral Electrical Stimulation: Toward Acquisition of Anxiety and Fear in Dental Procedures

Yusaku Minamibayashi
Graduate School of Science and Engineering
Aoyama Gakuin University
Kanagawa, Japan
yusaku.minamibayashi@x-lab.team

Shintaro Oka
Dental Hospital
Osaka University
Osaka, Japan
nozaki.kazunori.dent@osaka-u.ac.jp

Mai Kamihori
Graduate School of Science and Engineering
Aoyama Gakuin University
Kanagawa, Japan
mai.kamihori@x-lab.team

Ryota Ozaki
Graduate School of Science and Engineering
Aoyama Gakuin University
Kanagawa, Japan
ryota.ozaki@x-lab.team

Kazunori Nozaki
Dental Hospital
Osaka University
Osaka, Japan
nozaki.kazunori.dent@osaka-u.ac.jp

Yuichi Itoh
College of Science and Engineering
Aoyama Gakuin University
Kanagawa, Japan
itoh@it.aoyama.ac.jp

***Abstract*— Anxiety and fear related to dental care are significant factors that contribute to avoidance behavior toward dental visits. Dental phobia, a specific form of this fear, manifests as various symptoms in patients. Dental Anxiety Scale, Modified Dental Anxiety Scale, and Visual Analogue Scale are commonly used to assess the level of dental fear. However, these tools rely on subjective self-reports, making it challenging to quantitatively assess anxiety in another person. We believe that fear during dental procedures affects grip force. Therefore, we developed a rod-shaped device to measure it. In this paper, we define "grip force" as the continuous grasp force during a specific period. The device comprises pressure sensors, a microcomputer, an analog multiplexer, and a portable battery. We experimented to evaluate the relationships between the grip force and electrical stimulation of the oral cavity with 32 participants. By dividing the series of grip force data into three equal intervals and comparing the median of each interval, it was found that although there were individual differences in the change in grip force, it could be divided into five groups, including an upward and a downward trend.**

***Index Terms*— Grip force, Dental phobia, Classification, Change trend, Oral electrical stimuli**

I. INTRODUCTION

Anxiety and fear related to dental care are well-documented factors that contribute to avoidance behavior towards dental visits [1]–[3]. Among these, anxiety specifically related to dental treatment is termed "dental anxiety" [4]. The reaction to perceived threats during dental treatment is referred to as "dental fear" [3], which is a specific phobia associated with dental care [5], [6]. Dental phobia manifests as intense feelings of anxiety, fear, and dread in response to dental procedures and is often perceived as irrational or exaggerated threats. The DSM-V defines dental phobia as persistent and often unnecessary fear [7], [8]. Patients with dental phobia exhibit both visible symptoms, such as hyperventilation, hypertension, rapid heartbeat, and nausea, as well as less visible symptoms, including irrational fear, panic, and anxiety [6], all of which contribute to avoidance behavior. The Dental Anxiety Scale (DAS) [9] and its modified version, the Modified Dental Anxiety Scale (MDAS) [10], are widely recognized tools for assessing the level of dental anxiety and fear. The MDAS extends the DAS by including anxiety related to oral injections, making the two scales closely related. Additionally, the Visual Analogue Scale (VAS) [11], commonly used for pain assessment, has also been shown to be effective in evaluating anxiety about dental care [12]. As described above, there are a variety of diagnostic methods for dental phobia and numerous ways to assess anxiety associated with dental phobia [13]– [15]. Despite the availability of these diagnostic tools, they all rely on self-reported questionnaires, making evaluations subjective. This reliance on subjective data can limit the reliability of assessments and complicate the estimation of others' emotional states. Consequently, there is a need for objective methods to assess dental anxiety and fear. On the other hand, Sahar et al. have reported that variations in grip force on the steering wheel can serve as an indicator of stress experienced by drivers [16]. Additionally, research is being conducted to estimate a person's state using a chair-type device [17], [18]. These suggest that body movement including grip force could potentially be used to estimate anxiety and fear during dental treatment, although no study has specifically examined this application. We define "grip force" as the continuous grasp force during a certain period. In this study, we developed a rod-shaped device designed to measure grip force and investigated the changes in grip force in response to oral electrical stimulation. We use a device to deliver

979-8-3315-0543-1/24/$31.00 ©2024 IEEE

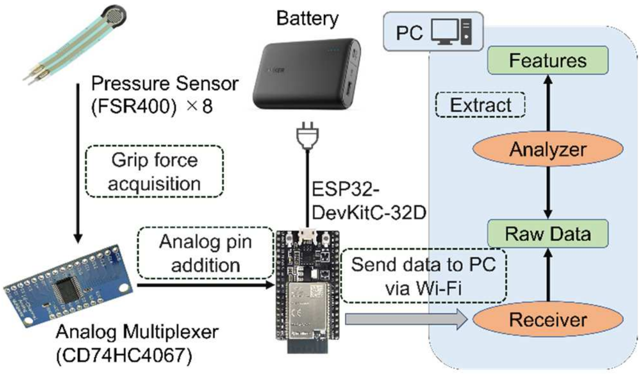


Fig. 1: System overview

electrical stimuli within the oral cavity to simulate conditions similar to those used in dental treatments. In this context, the oral cavity includes both the teeth, the main object of dental treatment, and the buccal mucosa, which may come into contact during treatment.

II. Proposed Method

Figure 1 shows the system overview implemented in this study. We hypothesized that muscle stiffness and grip force changes may occur when a subject experiences anxiety or fear. Based on this hypothesis, our system consists of a grip-type device to collect grip force data and a program to receive and analyze the data acquired by the device.

A. Gripping Device

The gripping device consists of pressure sensors (FSR400), a microcomputer (ESP32-DevKitC-32D), an analog multiplexer (CD74HC4067), and a portable battery. We use a portable battery (BI-B5, INIU) to power the ESP32 and the multiplexer to extend the number of available analog pins on the ESP32. The pressure sensors are connected to the ESP32, and the ESP32 transmits the acquired grip force data to the PC via Wi-Fi.

We developed the gripping part of the device as shown in Figure 2, using a 3D printer and a silicone rubber. As shown in Figure 3, the placement of the pressure sensors was designed concerning to "DataGrip", developed by Yamada et al. [19]. The diameter of the gripping part was set to 28.5 mm, following Yakou et al. [20].

B. Data Measurement

In this system, we measure the grip force by using eight pressure sensors attached to eight locations on the device. The sampling frequency of the grip force is 400 Hz, and the system records the elapsed time, grip force data from each pressure sensor, and the total grip force data for each device. We apply data filtering using the moving average method to remove the noise from the acquired data. The window size is 40, averaging the data collected over 0.1 seconds. We measure at 400 Hz, but since the main frequency of "tremor," a human physiological phenomenon, is around 10 Hz [21], we determined that sensing grip force at more than twice this frequency would be sufficient. Therefore, we downsample the filtered data to 30 Hz within the software.

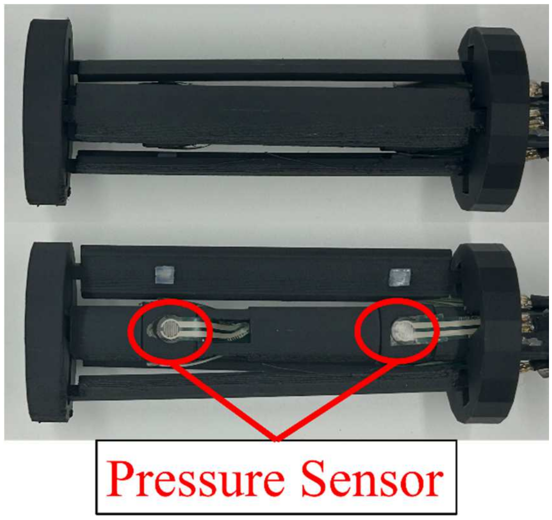


Fig. 2: Device geometry

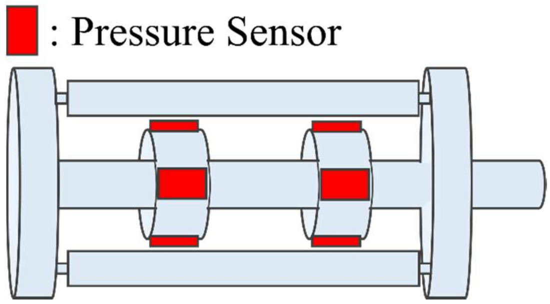


Fig. 3: Sensor layout

III. Experiment and Discussion

A. Experiment

As described in Chapter II, it is thought that changes in grip force are influenced when people experience anxiety or fear. Therefore, we conducted an experiment to observe how grip force changes in response to varying intensities of electrical stimulation applied to the oral cavity. The participants in our experiment consisted of 32 healthy undergraduate and graduate students (21 males and 11 females) whose average age was 20.3±1.9 years. The group included 27 right-handed and 5 left-handed participants. Before the experiment, we explained the procedure and obtained signed consent forms from all participants. In this experiment, we used the Digitest II (Parkell), a device commonly employed in dentistry to assess pulp vitality, to administer electrical stimuli in the oral cavity. The electrical stimulation level applied using this device increases by one unit approximately every 0.5 seconds, reaching a maximum of 64 levels. A licensed dentist delivered the stimulus. This study was approved by the ethics review board of our university (approval number: H24-021).

Figure 4 shows the experiment setup. Each participant was seated in a chair, gripped the device shown in Figure 2 with their dominant hand, and held the Digitest II counter electrode clip on

Fig. 4: Experimental setup

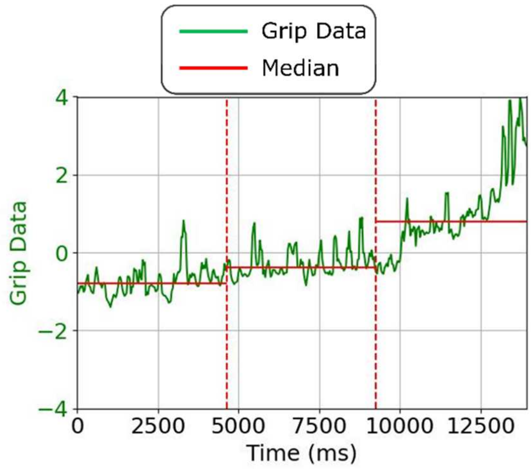


Fig. 5: Graph after splitting the standardized grip force data (vertical axis: grip force (after standardization), horizontal axis: time (ms))

the other hand. The experimenter then applied electrical stimuli to the participants' oral cavities. We instructed participants to stop the electrical stimulation upon feeling pain, and the stimuli terminated when they released the counter electrode clip. Each participant completed ten trials.

B. Results

In this experiment, data during the period when the electric stimulus was presented were extracted from the data after downsampling. To examine changes in grip force, we standardized the data from each trial such that the mean was 0 and the variance was 1. We presented the participants with the electrical stimuli 10 times and found that they became accustomed to the pain of electrical stimulation during the course of the experiment. Some participants noted that their anxiety and fear decreased with repeated electrical stimuli. Therefore, in this paper, we examine the data from the first trial, which is considered to be the most natural response to the electrical stimuli. We analyzed the data from 29 participants in the first trial, as data from 3 participants could not be obtained due to device malfunction.

To analyze the trend in grip force changes, we divided the standardized grip force data into three equal-time segments and compared the median values of each segment. The divided intervals are designated as "start," "mid," and "end" in order of the earliest time. Figure 5 shows an image of the division of the grip force data.

The Shapiro-Wilk test revealed that each participant's standardized grip force data did not follow a normal distribution; therefore, we conducted a Kruskal-Wallis test. Subsequently, we performed Bonferroni's multiple comparison test to examine significant differences in the data across the divided intervals.

The Kruskal-Wallis test revealed significant differences in the data of 27 of 29 participants ($p<0.01$). We classified the data of the 27 participants with significant differences into two patterns. Additionally, all 27 participants showed significant differences between start and end intervals ($p<0.01$).

I. Significant differences ($p<0.01$, $p<0.05$) existed in all intervals (23 persons)
II. 2 intervals have significant difference ($p<0.01$, $p<0.05$), 1 interval has no significant difference (4 persons)

In Pattern I, 19 participants showed significant differences across all intervals: start-mid, mid-end, and start-end ($p<0.01$). Three participants had significant differences in start-mid ($p<0.05$), mid-end ($p<0.01$), and start-end ($p<0.01$). One participant showed significant differences in start-mid ($p<0.01$), mid-end ($p<0.05$), and start-end ($p<0.01$). In Pattern II, three participants had significant differences in start-mid ($p<0.01$) and start-end ($p<0.01$). One participant had significant differences at the mid-end ($p<0.05$) and start-end ($p<0.01$).

C. Discussion

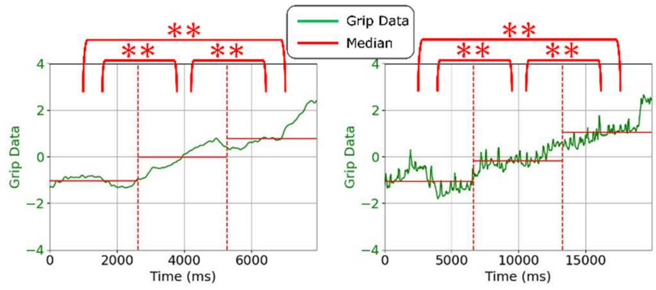
First, we discuss the 27 participants who showed significant differences in median values across intervals. As mentioned earlier, all the participants exhibited a significant difference between the start and end intervals ($p<0.01$). This indicates that, by comparing the beginning and end of the segmented intervals, we can identify whether there is an upward or downward trend in the grip force.

For the participants in Pattern I, significant differences ($p<0.01$, $p<0.05$) were observed across all three intervals. This suggests that their grip force changed over time.

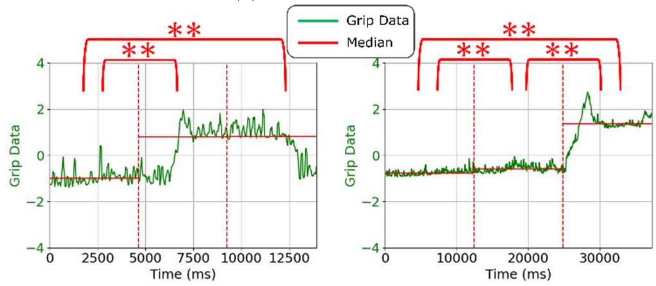
Participants in Pattern II showed no change in the grip force within the interval, for which we found no significant difference. However, since there was a significant difference between the start and end intervals ($p<0.01$), it is likely that a rapid change in grip force occurred within the intervals where significant differences were observed, either between the start-mid or the mid-end.

For the two experimental participants, for whom there were no significant differences in the median values of all intervals, it is considered that little change in grip force occurred.

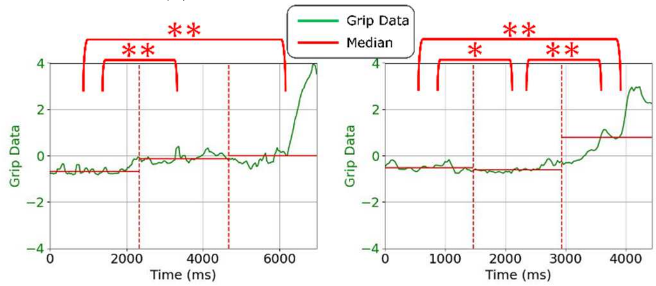
Based on the above analysis and a subjective evaluation through visual inspection of the data, we classified the data of the 29 participants into five groups (1-5), further categorized into two major categories (a, b). Representative graphs for each group (1-5) are shown in Figure 6.



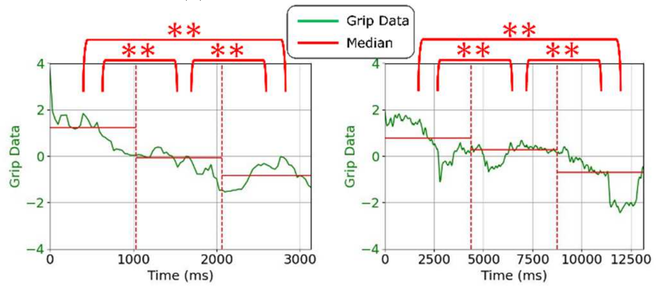
(a) Gradual increase



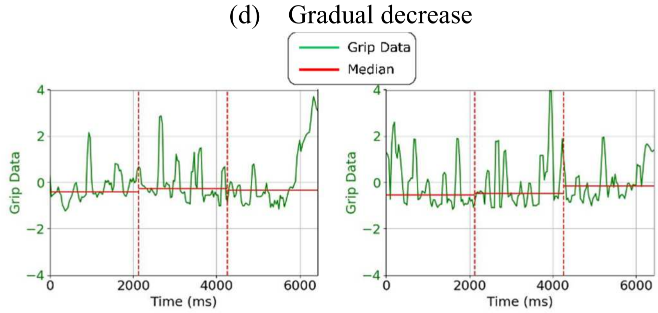
(b) Sudden increase in the middle



(c) Sudden increase at the end



(d) Gradual decrease



(e) No change

Fig. 6: Graphs by group (vertical axis: grip force (after standardization), horizontal axis: time (ms), *: p<0.05, **: p<0.01)

1. gradual increase (13 persons)
2. sudden increase in the middle (5 persons)
3. sudden increase at the end (5 persons)
4. gradual decrease (4 persons)
5. no change (2 persons)

a. upward trend (1, 2 and 3 combined, 23 persons)
b. Trend of rapid increase (2, 3 combined, 10 persons)

Group 1 consisted of 13 individuals from Pattern I, characterized by a gradual increase in grip force over time.

Group 2 included three participants from Pattern I and two from Pattern II. Group 3 comprised three participants from Pattern I and one from Pattern II. Some data in Pattern I show sudden changes in the grip force, as illustrated on the right side of Figure 6(b). Additionally, most participants in Pattern II exhibited abrupt changes in the grip force within the intervals where significant differences were observed. However, there were exceptions, such as the left side of Figure 6(c), where a rapid increase in grip force was noted despite the absence of significant differences.

Group 4 included three participants from Pattern I and one from Pattern II. Since there were no abrupt changes in values for the downward trend, we compared the median values of start and end, classifying those with a higher end value into Group 4.

Group 5 consisted of two participants whose median differences were not statistically significant.

For major category "a", we categorized participants with significant differences between the start and end, with a higher end median. Major category "b" included participants from Groups 2 and 3, who exhibited a rapid increase in response.

The grouping results based on changes in grip force revealed that 23 of 29 participants showed increased grip force in response to oral electrical stimuli. However, four participants tended to decrease their grip force. This indicates that while there is a strong tendency for grip force to increase in response to oral electrical stimuli, individual differences exist, and an increase in grip force is not guaranteed. We aim to investigate these differences further in future studies.

Additionally, 9 of the 13 participants in Group 1 reported enduring pain during the experiment. Since the intensity of the electrical stimulus increased over time, there may be a correlation between grip force and pain.

We found that grip force changes could be classified into five patterns, so if patients could be classified into these five patterns in advance through some form of testing, it may be possible to estimate their anxiety and fear. However, this remains a task for future research. In this study, we focused solely on grip force, having participants grasp the device. However, if the device were fixed to an armrest and participants were instructed to grip it, it may be possible to improve accuracy by measuring not only the grip force but also the muscle tension of the entire arm.

In dental treatment, it is necessary to adopt approaches that respond to changing trends in patients' grip force. In the future, we plan to explore possible approaches. We aim to develop a system that facilitates regular dental care for patients with dental phobia, ultimately creating a more accessible and patient-friendly dental environment.

IV. Conclusion

In this paper, we proposed a rod-shaped device equipped with a pressure sensor and implemented a system to measure grip force in response to oral electrical stimulation. We conducted experiments in which grip force data were collected from 32 participants while applying electrical stimulation to the oral cavity, and we analyzed the resulting changes. We divided the collected data into three equal time intervals and compared each interval. We classified the grip force into five groups and two major categories based on the intervals' significant differences and median values. In the future, we aim to develop a system that facilitates easier access to dental clinics by further examining the differences in grip force tendencies and exploring patient-specific approaches in dental treatment settings.

Acknowledgment

This work was partially supported by JSPS KAKENHI Grant Number JP24H00745.

References

[1] R. J. Gatchel, B. D. Ingersoll, L. Bowman, M. C. Robertson, and C. Walker, "The prevalence of dental fear and avoidance: A recent survey study," *The Journal of the American Dental Association*, vol. 107, no. 4, pp. 609–610, 1983.

[2] V. Pohjola, S. Lahti, M. M. Vehkalahti, M. Tolvanen, and H. Hausen, "Association between dental fear and dental attendance among adults in finland," *Acta Odontologica Scandinavica*, vol. 65, no. 4, pp. 224–230, 2007.

[3] D. P. Appukuttan, "Strategies to manage patients with dental anxiety and dental phobia: literature review," *Clinical, Cosmetic and Investigational Dentistry*, vol. 8, pp. 35–50, 2016.

[4] S. Agras, D. Sylvester, and D. Oliveau, "The epidemiology of common fears and phobia," *Comprehensive Psychiatry*, vol. 10, no. 2, pp. 151– 156, 1969.

[5] H. S. Bracha, E. M. Vega, and C. B. Vega, "Posttraumatic dental-care anxiety (ptda): Is "dental phobia" a misnomer?" *Hawaii dental journal*, vol. 37, no. 5, pp. 17–19, 2006.

[6] H. Singh, D. Bhaskar, and R. Rehman, "Psychological aspects of odontophobia," *Int J Dent Med Res*, vol. 1, no. 6, pp. 210–212, 2015.

[7] M. B. First, "Diagnostic and statistical manual of mental disorders, 5th edition, and clinical utility," *The Journal of Nervous and Mental Disease*, vol. 201, no. 9, pp. 727–729, 2013.

[8] N. Avramova, "Dental fear, anxiety, and phobia; causes, diagnostic criteria and the medical and social impact," *Journal of Mind and Medical Sciences*, vol. 9, pp. 202–208, October 2022.

[9] N. L. Corah, "Development of a dental anxiety scale," *Journal of Dental Research*, vol. 48, no. 4, p. 596, 1969.

[10] G. Humphris, T. Morrison, and S. Lindsay, "The modified dental anxiety scale: validation and united kingdom norms," *Community dental health*, vol. 12, no. 3, pp. 143–150, September 1995.

[11] R. C. Aitken, "A growing edge of measurement of feelings [abridged]: Measurement of feelings using visual analogue scales," *Proceedings of the Royal Society of Medicine*, vol. 62, no. 10, pp. 989–993, 1969.

[12] E. Facco, G. Zanette, L. Favero, C. Bacci, S. Sivolella, F. Cavallin, and G. Manani, "Toward the validation of visual analogue scale for anxiety," *Anesthesia Progress*, vol. 58, no. 1, pp. 8–13, Jan. 2011.

[13] C. D. Spielberger, "State-trait anxiety inventory," in *The Corsini Encyclopedia of Psychology*, I. B. Weiner and W. E. Craighead, Eds. John Wiley & Sons, Ltd, 2010.

[14] A. T. Beck, N. Epstein, G. Brown, and R. A. Steer, "An inventory for measuring clinical anxiety: Psychometric properties," *Journal of Consulting and Clinical Psychology*, vol. 56, no. 6, pp. 893–897, 1988.

[15] A. S. Zigmond and R. P. Snaith, "The hospital anxiety and depression scale," *Acta Psychiatrica Scandinavica*, vol. 67, no. 6, pp. 361–370, 1983.

[16] Y. Sahar, T. Elbaum, M. Wagner, O. Musicant, T. Hirsh, and S. Shoval, "Grip force on steering wheel as a measure of stress," *Frontiers in Psychology*, vol. 12, 2021.

[17] K. Nishimura, K. Ito, K. Fujiwara, K. Fujita, and Y. Itoh, "Detection of nodding of interlocutors using a chair-shaped device and investigating relationship between a divergent thinking task and amount of nodding," Quality and User Experience, vol. 8, no. 1, p. 10, October 2023.

[18] M. Manabe, K. Fujiwara, K. Ito, and Y. Itoh, "The association between synchrony and intellectual productivity in a group discussion: a study using the sensechair," Humanities and Social Sciences Communications, vol. 11, no. 1, p. 229, February 2024.

[19] T. Yamada and T. Watanabe, "Development of a small pressure-sensor-driven round bar grip measurement system for infants," *TRANSACTIONS OF THE JAPAN SOCIETY OF MECHANICAL ENGINEERS Series C*, vol. 79, pp. 743–747, March 2013.

[20] T. Yakou, K. Yamamoto, M. Koyama, and K. Hyodo, "Sensory evaluation of grip using cylindrical objects," *JSME International Journal Series C*, vol. 40, no. 4, pp. 730–735, 1997.

[21] J. Raethjen, F. Pawlas, M. Lindemann, R. Wenzelburger, and G. Deuschl, "Determinants of physiologic tremor in a large normal population," *Clinical Neurophysiology*, vol. 111, no. 10, pp. 1825–1837, 2000.