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MyCmp: Temporomandibular Joint Disorder Monitoring and Regulation System

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Abstract. Temporomandibular disorder (TMD) is a common musculoskeletal disease in the oral and maxillofacial regions. It is a complex syndrome mainly characterized by pain, popping, and abnormal joint movement in the temporomandibular joint area of the affected side. The masticatory muscle, temporomandibular joint, and related structures are involved. The pathogenesis of masticatory muscle, temporomandibular joint, and related structures is still unclear. As a wearable device with high social acceptance and widespread use, we designed a customized frame for glasses to monitor temporomandibular chewing movement data collection and generate a learning model. The temporomandibular joint disorder database was constructed to assist stomatologists in diagnosis and to help customize personalized precision treatment models for patients. We propose MyCmp to capture chewing signals and achieve accurate temporomandibular joint chewing data collection by combining piezoelectric sensors and motion sensors. We also propose a practical method that combines temporomandibular joint disorders with artificial intelligence, and we designed test experiments to evaluate the practical application of MyCmp. It is our hope that the development and use of MyCmp can benefit patients with TMJ disorders.

Keywords. Temporomandibular joint disorder, disorder detection, multi-modal, sensor, wearable device

1. Introduction

The temporomandibular joint (TMJ) consists of the mandibular head, the temporomandibular fossa, and the articular tuberosity. It is a joint between the left and right sides of the jaw, governing the opening and closing of the mouth and mastication. Temporomandibular disorders (TMD) are common musculoskeletal disorders of the oral and maxillofacial region, the pathogenesis of which is not yet fully understood. Clinical manifestations include pain in the joint area, joint popping during movement, and impaired jaw movement. This poses a significant challenge to clinicians in designing individualized treatment plans for patients with TMD[1].Currently, the diagnosis of TMJ

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disorder relies on clinical assessment and magnetic resonance imaging (MRI). However, it has been found that there is wide variation in the agreement between the position of the articular disc on MRI and the clinical symptoms, ranging from 59% to 90%[2].This presents a substantial challenge to physicians in creating customized treatment plans for patients. Addressing how to provide accurate diagnosis and precise treatment for patients with TMJ disorders is the next question we will tackle.

At present, it is known that most diagnoses and treatments of TMD are based on conservative approaches, and the probability of therapeutic effectiveness remains unclear. Therefore, the diagnosis of TMD and the choice of a treatment plan are of paramount importance. Different TMD classifications require corresponding treatment plans, and combinations of different treatments can be considered[3]. To address these challenges, we conducted extensive research to develop a TMJ disorder monitoring and adjustment system. This system helps collect TMJ movement data for monitoring and adjusting masticatory habits. To broaden its applicability and practicality, the TMJ disorder monitoring and adjustment system must provide accurate monitoring while being energy-efficient in various environments. Through our research, we found that using glasses as a socially acceptable wearable device offers an effective solution. By attaching the monitoring system to glasses, we achieve precise monitoring. Placing the glasses close to the mouth is conducive to proper detection and identification of TMJ movements.

We have developed MyCmp (My Conditioning Monitoring Partner), a TMJ motion monitoring system attached to eyeglasses. Our development is divided into two parts: the first part involves MyCmp's use of two sensors to achieve accurate chewing signal capture, accomplished by combining piezoelectric sensors and accelerometers. The second part of our development is the direct attachment of these sensors to eyeglasses, eliminating the need for custom personalized frames.To ensure the reliability and evaluation of the MyCmp (My Conditioning Monitoring Partner) TMJ motion monitoring system we developed, we built a prototype and collected real data from users in real-world scenarios. The primary purpose of this data collection is to assess the system's accuracy and its adaptability in various scenarios. Over the course of a week, we collected TMJ movement trajectories from users throughout the day and accurately monitored the data. This data was then compared with MRI images to evaluate the MyCmp (My Conditioning Monitoring Partner) TMJ motion monitoring system we developed.The MyCmp (My Conditioning Monitoring Partner) temporomandibular joint motion monitoring system was designed to evaluate the system's rationality, accuracy, and applicability.

2. Background and Related Work

2.1. Diagnosis of temporomandibular joint disorder

Temporomandibular joint disorder (TMD) is one of the four most common diseases in the oromandibular system[4]. The clinical symptoms include pain, dyskinesia, joint popping/murmur, and headache, which are more common in young adults and significantly more common in women than men. Therefore, raising awareness of the disease among clinicians[6-7], and prompt diagnosis and treatment can reduce further damage.

Clinical symptoms of temporomandibular joint disorder (TMD) include TMJ pain, TMJ murmur, restricted mouth opening, occlusal distress, and joint popping. While these symptoms are not threatening, prolonged untreated symptoms can become more pronounced and affect the patient's psychological well-being and quality of life. The diagnosis is made clinically, in conjunction with MRI, which is one of the most complex parts of the body and is not as accurate as it could be.

With the increase in the attendance of such patients, accurate diagnosis is particularly important. Magnetic resonance imaging (MRI) is the imaging method of choice for diagnosing displaced articular discs. It is non-invasive, involves no exposure to ionizing radiation, and provides clear imaging of soft tissues[5]. However, it has been found that there is a wide variation in the agreement between the position of the articular disc shown in MRI and the diagnosis of clinical symptoms, ranging from 59% to 90%[2]. This also places significant pressure on clinicians to provide accurate diagnoses and develop treatment plans for patients.

2.2. Detection of temporomandibular joint disorder

Detection and diagnosis of temporomandibular joint disorder are currently based on clinical assessment using dental imaging, with two widely used modalities: the first involves X-ray radiographs, and computed tomography (CT) scans are commonly employed as auxiliary imaging tests for diagnosing TMD. However, CT diagnosis has faced criticism due to its limitations in observing soft tissues and intra-articular fluid around the TMJ.The second modality is magnetic resonance imaging (MRI), which has become increasingly popular with advances in imaging technology. MRI can effectively detect soft tissue structures around the TMJ and intra-articular effusion, but it may still fall short of providing dentists with the precise information needed to tailor treatment plans for individual patients.

Several studies[8-10]have explored the correlation between MRI manifestations and clinical symptoms in patients with TMD, primarily focusing on the relationship with. Koca et al.[8]evaluated clinical and MRI data from both bilateral joints in 350 individuals with TMD. They concluded that joint pain was associated with displacement of the articular disc, degenerative changes in the condylar bone, joint effusion, and deformation of the articular disc structure. Takahara et al[9].reported that increased ADDWoR (Additive of Anterior and Posterior Disc Displacement) and joint effusion were strongly linked to pain. HostGator et al.[10]also found that significant joint effusion was statistically associated with joint pain. Given this context, understanding the relationship between clinical symptom presentation and TMJ joint changes in patients with TMD is essential for accurately determining and preventing functional impairment resulting from abnormal changes. It is also crucial for developing appropriate treatment plans.

2.3. Treatment related to temporomandibular joint disorder

- TMD uses body posture therapy

In recent years, many researchers have suggested a correlation between TMD and body posture, making postural adjustment a new treatment modality for TMD patients. A two-month review revealed that the patient's masticatory muscles returned to their previous levels. This suggests that CPR therapy can effectively treat patients with TMJ disorder, but this method requires long-term self-adjustment of posture[11].

- TMD treated with an occlusal plate

Occlusal plates are currently a common treatment used in dentistry for patients with TMD. Patients wear a stabilized dental pad for several months to observe TMJ changes in patients with TMJ disorder. Some patients have reported improvements in clinical symptoms while wearing the occlusal plate. However, many patients find that the occlusal plates are not comfortable for long-term wear and do not fit all patients. They are not suitable for patients with existing temporomandibular problems or those undergoing orthodontic treatment with braces.

We developed MyCmp (My Conditioning Monitoring Partner), a TMJ movement monitoring system integrated with glasses. Our system serves two primary purposes:Firstly, it provides a comprehensive record of TMJ movement for patients experiencing TMJ disorder-related symptoms. It records biting patterns, oral opening and closing movements, and establishes an individualized medical history data collection, along with creating a digital model of the TMJ. We integrate artificial intelligence to learn from this model and generate a digital representation of the TMJ. This tool assists doctors in tailoring precise treatment plans for each patient.Secondly, the captured data will be linked to the app we plan to develop in the future. This app will serve as a reminder for patients to maintain correct chewing and biting postures. By improving their posture, we aim to treat TMJ disorder patients effectively.

3. Design Process

To establish the feasibility of implementing the MyCmp (My Conditioning Monitoring Partner) TMJ motion monitoring system, we first discussed its rationale with experts, then explored design options with our mentor, and finally presented the process and goals of our design.

3.1. Design Survey

We conducted a preliminary survey by consulting three individuals: one TMJ research specialist with over 10 years of experience, one specialist with more than 5 years of experience in the study of oral dental occlusion, and one patient diagnosed with TMJ disorder who has over 5 years of experience from Southern Medical University Dental Hospital in Guangdong Province, China. Our communication sessions involved a mean age of 40 (SD = 9.37) and were identified as K1, K2, and K3.The survey interviews lasted between 50 to 90 minutes, during which we presented our ideas on TMJ disorder detection, introduced the MyCmp (My Conditioning Monitoring Partner) TMJ motion monitoring system, engaged in discussions, and gathered their perspectives on our research topic.TMJ researchers believe that a real-time and accurate system for detecting TMJ motion trajectories would be highly beneficial for clinicians. Oral and dental occlusion experts emphasized the strong relationship between TMJ disorder patients and the muscular tissues around the temporomandibular joint. They identified one significant contributing factor as a long-term incorrect chewing pattern. They believe that MyCmp can autonomously guide patients to chew correctly, offering a valuable treatment option for TMJ patients.Patients diagnosed with TMJ disorder expressed their anticipation for MyCmp, stating, "It would be great to diagnose TMJ disorder without the need for surgery, and having a correct bite reminder is exactly what we need."Several recommendations emerged from these discussions:(i) K1 and K2 proposed the creation of a database of correct occlusions for various dental models to ensure accurate treatment.(ii) K3 suggested that MyCmp should be designed with the user's comfort in mind, considering the scenario in which it will be worn.

3.2. Design Objectives

After conducting preliminary research and discussing related work with psychologists, we identified key tasks that should be incorporated into an interactive system to guide the construction of the system:(1) The designed system should seamlessly integrate sensors with existing commercially available eyewear and should not be limited by specific materials and frame shapes.(2) The system should aim for an extended range to meet requirements while integrating low-power sensors.(3) Precise capture of TMJ motion signals is crucial for achieving accurate sensitivity.(4) The system's appearance should be adaptable to various scenarios and must prioritize comfort for wearers.

4. System Description

As part of our preliminary design research and discussions with experts, we developed a text model and conducted initial tests. Hardware refers to the integration of piezoelectric and accelerometer sensors on MyCmp, and we capture TMJ motion signals using the combination of these two sensors, as illustrated in Figure 1. The software design is connected to an app that reports the signals captured by the sensors, generating temporomandibular motion trajectory data throughout the day.

4.1. Hardware Design

The hardware refers to a combination of piezoelectric and accelerometer sensors on the MyCmp. We use this combination of sensors to capture the temporomandibular motion signal, as illustrated in Figure 1. The piezoelectric sensor is employed to detect temporomandibular and temporal muscle contractions during oral occlusion. This muscle contraction generates significant mechanical dynamic forces on the skin, making it more easily perceivable. For the piezoelectric sensor, we utilized a thin-film pressure sensor, as shown in Figure 2, which can make direct contact with the skin to obtain accurate sensing signals. We integrate the piezoelectric sensor with the glasses, ensuring natural contact with the skin to monitor the TMJ movement trajectory without causing user discomfort.

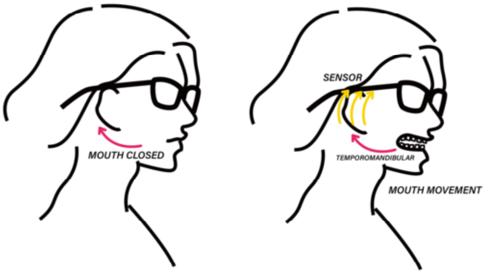

Figure 1. Temporomandibular motion trajectory signal capture.

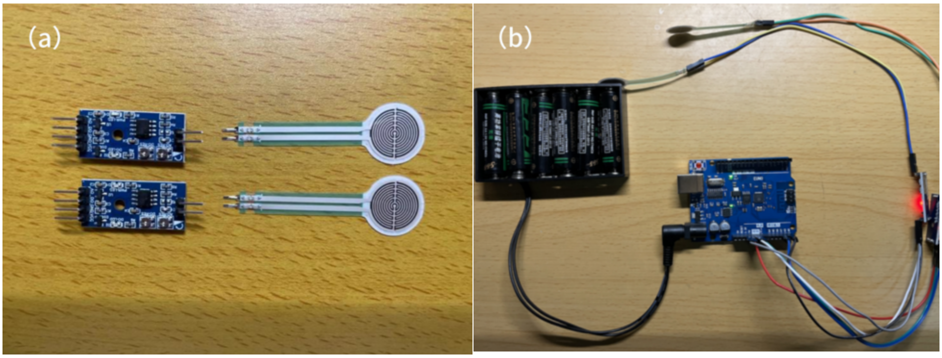

Figure 2. (a)Thin Film Pressure Sensors. (b)Sensor combination method.

4.2. Hardware construction and assembly

After completing the design, we integrated the piezoelectric sensors into the eyeglass frame for practical testing. To ensure user comfort without interference from other activities, we positioned the piezoelectric sensors on both sides of the eyeglass legs, close to the temporomandibular muscle occlusion point and near the upper zygomatic bone position. We also equipped the system with an ESP to provide sufficient computing power for running the deep learning model. Both wires were installed on either side of the eyeglass legs and connected to the ESP device, as illustrated in Figures 3 and 4.

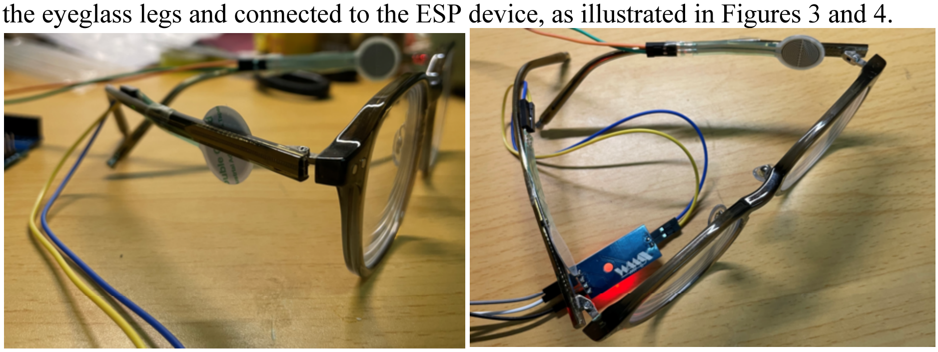

Figure 3 and Figure 4. Hardware construction and assembly method.

The piezoelectric sensor unit and the Bluetooth module are positioned on both sides of the glasses' legs. The design has undergone multiple tests to ensure accurate monitoring. The piezoelectric sensor unit and Bluetooth module are located on the inside of the legs, with an outer plastic wrap. To avoid drawing attention to the user's appearance and to protect the sensors and circuitry from external exposure, we have redesigned the appearance of MyCmp to achieve an aesthetic effect, as illustrated in Figure 5.

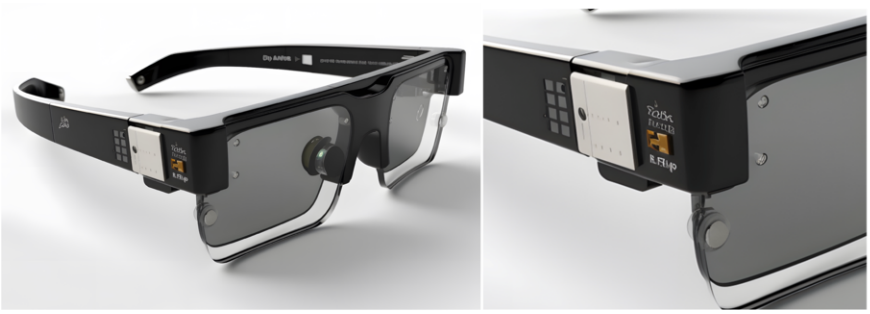

Figure 5. MyCmp exterior design.

4.3. Temporomandibular joint occlusion monitoring system design

We developed MyCmp (My Conditioning Monitoring Partner), a TMJ motion monitoring system, and designed the system framework of MyCmp, as depicted in Figure 6. For our hardware, we utilized a combination of piezoelectric sensors and accelerometers to collect various data points, including (i) the angle of mouth opening and closing, (ii) TMJ changes during food chewing, (iii) yawning and other scenarios requiring wide mouth opening that affect the TMJ and mandibular joint movements in occlusal posture.To process this data, we employed the ESP32 microcontroller for data preprocessing. The processed data is then transformed and relayed to the TEM GLASS APP via Python processing. We have designed a visualization page to present this data to TMJ disorder patients. These data are saved in real-time and utilized for AI learning. This AI learning process generates a dedicated personal database, accessible to physicians for tailoring treatments to individual patients.To prioritize user privacy, we ensure that raw data remains confidential and is not shared with external parties.

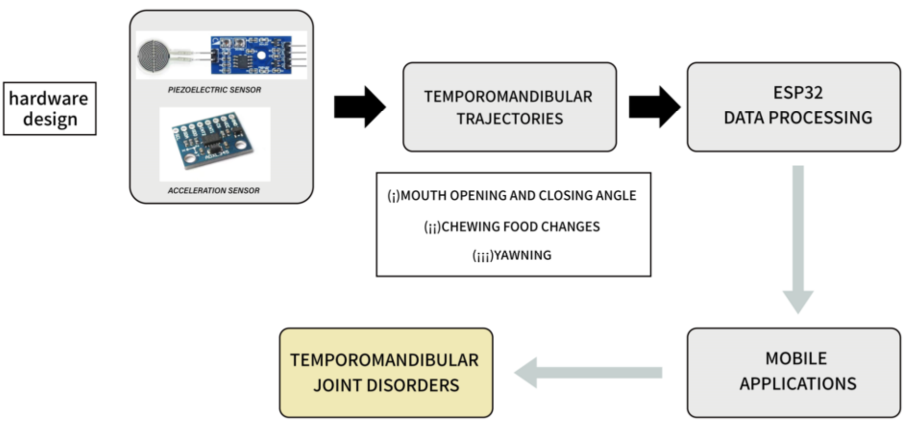

Figure 6. MyCmp's system framework.

4.4. Software Design

We use librosa with Python to analyze all TMJ trajectory data extracted on the server and process it into the TEM GLASS APP. TMJ disorder patients can review their TMJ movement data throughout the day, assess their bite patterns for correctness, identify any incorrect chewing patterns, and receive data collection and reminders. Additionally, the TEM GLASS APP is designed to monitor postural adjustments and prompt users to maintain correct posture, as discussed in section 2.3.1. The long-term adoption of proper posture can significantly assist in treating TMJ disorder patients.Within TEM GLASS, we establish a closed chain that, in addition to data collection, provides dietary recommendations for foods that TMJ disorder patients should avoid. The data is organized by individual, ranging from daily records to weekly, monthly, and annual data.

Figure 7. TEM GLASS APP design and data analysis.

5. Initial user research

To assess the feasibility of MyCmp (My Conditioning Monitoring Partner), a TMJ motion monitoring system, and to gauge patient perceptions of MyCmp, we conducted a preliminary user study. In collaboration with Guangdong Provincial Dental Hospital, we recruited four patients diagnosed with TMJ disorder for over 5 years. These users were designated as K1, K2, K3, and K4, with a mean age of 35.7 years. All participants had experienced TMJ disorder symptoms such as joint popping and TMJ pain for more than 5 years and volunteered to participate in the study. To test the real-world, long-term usability of MyCmp, we conducted the study in a natural environment outside the laboratory. Participants provided consent for the recording and documentation of the entire process.

5.1. Procedures

The experiment was a 10-hour experience for four participants who chose to return the equipment and a week-long study for those who wished to continue. All four participants, including college students and office workers, were habitual eyeglass wearers. On the study day, participants arrived at the lab in the morning to collect their MyCmp glasses and downloaded the TEM GLASS app for a day of data collection. Throughout the morning, participants engaged in their usual daily activities. In the evening, they returned to the lab to return the equipment and participate in a semi-structured interview.

- How comfortable is it to wear MyCmp glasses?
- Is the TEM GLASS APP data self-perception accurate?
- Is the TEM GLASS APP effective in reminding the mouth opening function?

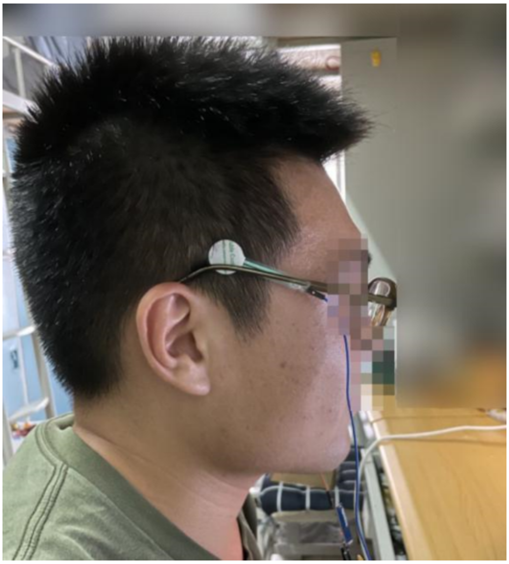

Figure 8. Participants try it on.

5.2. *Results*

In our formal interviews with the participants, K1 smiled and said, "The TEM GLASS APP's posture reminder feature subconsciously makes me pay attention to the angle of mouth opening and closing, and as a result, my joints pop much less throughout the day." K3 expressed, "Wearing it hasn't seemed to affect my daily activities, and I find the test data quite accurate personally. It even detected when I yawned and reminded me to be mindful of my mouth's movements." Both K1 and K3 have hopes for future improvements. They mentioned concerns about the current exposure of the sensor and wires, which could be problematic when exposed to water. They hope that, in the future, there will be a protective shell for the glasses, concealing the sensor and wires within.

Interestingly, an examination of K4's data revealed some undetected TMJ motion. When asked about the circumstances surrounding the false alarm, K4 responded, "I was wearing headphones, which might have caused them to come into physical contact with MyCmp, potentially affecting the monitoring system's detection data.

Overall, all participants expressed confidence in the usefulness of MyCmp glasses for treating TMJ disorder. My findings indicate that MyCmp glasses provide an effective means of collecting data and treating TMJ disorder patients.

Table 1. User Survey Results

Question	K1	K2	K3	K4	Average
1. Are you willing to wear MyCmp glasses for a long time? (1:willing - 6: unwilling)	5.7	6	6	5.8	5.9
2. Do you have confidence in the data detected by MyCmp glasses? (1: Yes - 6: No)	5.2	5.5	6	5.3	5.5
3. Do you think wearing MyCmp glasses has affected your normal life? (1: Yes - 6: No)	6	5.7	5.8	5.7	5.8
4. Has the reminder function of MyCmp glasses helped you to be actively aware of temporomandibular movements? (1: Yes - 6: No)	5.8	5.6	5.4	6	5.7

6. Limitations and future work

Firstly, it's important to note that MyCmp glasses may not be suitable for patients who are unwilling to wear glasses. Our research indicates that glasses are the most socially accepted wearable device. However, for users unaccustomed to wearing glasses, this may be a limitation of MyCmp. Often, the reluctance to wear glasses stems from not being accustomed to them or finding them unattractive. Nevertheless, we believe that as smart glasses become more prevalent in society, this situation may change.Secondly, in the initial development of MyCmp glasses, the sensors and wires were exposed. However, we plan to address this issue in the subsequent iterations of our design.

We will update and iterate MyCmp glasses in the future based on user feedback to improve data detection accuracy.

7. Conclusion

In this paper, we introduce MyCmp glasses, a data collection system that accurately detects TMJ trajectories in patients with TMJ disorder. It also incorporates a reminder function that combines Global Postural Reeducation (GPR) with real-time reminders to assist patients in regulating their posture and improving TMJ disorder. By integrating Global Postural Reeducation (GPR) into the real-time reminder function, we aim to enhance the treatment of TMJ disorder. The collected TMJ motion data can be provided to physicians to help customize treatment plans for individual patients. We have achieved accurate detection by combining piezoelectric sensors with accelerometers. User studies have demonstrated that MyCmp glasses, in conjunction with the TEM GLASS APP, facilitate data collection and analysis. We conducted real-world data collection from four patients outside the lab throughout the day, confirming the accuracy of our design in detecting TMJ motion.We believe that the MyCmp glasses we have developed can significantly benefit TMJ disorder patients and will be a valuable tool for their subsequent treatment.

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