PERIODONTAL MECHANORECEPTOR CONTRIBUTION TO MINIMAL HOLDING FORCE BETWEEN INCISOR TEETH

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ABSTRACT

Objective: Periodontal mechanoreceptors (PMRs) are essential for fine regulation of incisal forces and oral object discrimination. This study aimed to quantify the contribution of PMRs to minimum holding force and to determine the influence of body position and periodontal health.

Methods: A lightweight force transducer (4 g; resolution 4 mN) was positioned passively between the maxillary and mandibular incisors and held against gravity without manual assistance. Minimum holding force was measured in sitting and prone positions before and after local anaesthesia of the incisors. Periodontal and gingival health were assessed and correlated with force measurements.

Results: In the sitting position, the mean minimum holding force was 0.63 N and increased to 1.87 N following local anaesthesia. In the prone position, values were 1.23 N and 2.63 N, respectively. Minimum holding force differed significantly across subjects and body positions.

A significant association between periodontal health and holding force was observed only under anaesthetised conditions.

Conclusion: Periodontal afferent input plays a critical role in fine control of incisal force. Loss of PMR function markedly reduces force sensitivity and appears to increase reliance on alternative proprioceptive inputs. These findings underscore the functional importance of periodontal integrity for oral sensorimotor performance and may have implications for periodontal and restorative treatment planning.

INTRODUCTION

Teeth are not rigidly ankylosed to the jaws but are suspended within the alveolar bone by the periodontal ligament (PDL), a specialised connective tissue that permits small, controlled tooth displacements during function (Grigoriadis et al., 2018, 2019). Embedded within the PDL are highly sensitive periodontal mechanoreceptors (PMRs) that respond to forces applied to the teeth in multiple directions (Trulsson, 2006). Even minimal tooth displacement can generate stress and strain within the ligament, activating low-threshold afferents (Cash et al., 1982).

PMRs transmit sensory input to the trigeminal brainstem nuclei, where they critically regulate and coordinate jaw movements (Lund, 1991; Trulsson et al., 1996a,b; Piancino et al., 2017; Grigoriadis et al., 2018, 2019). Their discharge properties are characterised by high sensitivity to low force levels, particularly in anterior teeth, where receptor firing increases steeply below approximately 1 N (Trulsson et al., 1996a,b). This encoding enables precise modulation of bite force during object manipulation and the early phases of mastication. Sensory feedback from PMRs enables rapid feedforward adjustment of motor output, ensuring efficient food breakdown while preventing excessive loading (Haraldson, 1983; Türker, 2002).

The functional importance of PMRs is underscored by studies demonstrating impaired force control when periodontal input is reduced or absent. Individuals with dental implants or complete dentures, who lack functional periodontal afferents, exhibit increased and more variable bite forces during food handling and object holding (Trulsson et al., 1998; Svensson

et al., 2011). Similarly, transient elimination of periodontal input by local anaesthesia results in elevated incisal holding forces (Johnsen et al., 2007; Svensson et al., 2009). Previous work reported that the minimum force required to hold an object between the incisors is approximately 1 N in dentate individuals, increasing nearly fourfold following local anaesthesia (Trulsson et al., 1998).

Despite these observations, experimental data on incisal holding force remain limited. Prior studies required subjects to hold the force transducer manually during a hold-then-bite paradigm, which may have influenced force control strategies. Moreover, the potential influence of body position and periodontal health status on holding force has not been systematically examined. Periodontal disease, characterised by loss of attachment and increased tooth mobility, may alter mechanoreceptive function and sensory-motor integration (Johansson et al., 2006), yet its impact on fine incisal force control is unclear.

The present study replicates and extends earlier investigations of incisal holding force using a lightweight, high-resolution force transducer capable of detecting forces as low as 4 mN. Unlike previous designs, the device was held passively between the incisors without manual assistance. Minimum holding force was recorded in both sitting and prone positions, before and after local anaesthesia of the anterior teeth, and correlated with indices of periodontal and gingival health.

We hypothesised that (1) minimum incisal holding force is lower and more variable than previously reported when measured without manual stabilisation, and (2) holding force increases with reduced periodontal sensory integrity, as reflected by local anaesthesia and worsening periodontal health. By refining the measurement paradigm, this study aims to further delineate the functional contribution of periodontal mechanoreceptors to fine oral force control.

MATERIALS AND METHODS

Participants

Twenty healthy adults (12 females, 8 males; mean age ± SD: 23.2 ± 1.9 years) with natural, non-crowded dentition and no history of orthodontic treatment, periodontal therapy within the previous 6 months, or temporomandibular disorders were recruited. Exclusion criteria

included systemic disease affecting neuromuscular function, medications that influence sensory or motor performance, and current orofacial pain.

The study protocol was approved by the Koç University Human Research Ethics Committee (2017.124.IRB2.038) and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to participation.

Force Transducer

Incisal holding force was measured using a FlexiForce™ piezoresistive sensor (Tekscan Inc., Boston, MA, USA). The sensor consisted of two polyester substrates coated with conductive silver and pressure-sensitive ink (0.203 mm thick). Applied force reduced electrical resistance in proportion to load.

The transducer had a response time of 50 μs, a force resolution of 4 mN, and a measurement range of 0.004–10 N. The active sensing area was positioned between the maxillary and mandibular central incisors. For hygiene, the sensor assembly was covered with a sterile transparent film and replaced between participants.

Experimental Design

A within-subject repeated-measures design was used. Minimum holding force was assessed under four conditions:

1. Sitting – without anaesthesia
2. Prone – without anaesthesia
3. Sitting – with local anaesthesia
4. Prone – with local anaesthesia

The order of sitting and prone positions was randomised. All non-anaesthetised trials were completed before local anaesthesia was administered. Participants were familiarised with the apparatus prior to testing and were blindfolded during data collection to eliminate visual feedback.

The transducer was positioned between the upper and lower central incisors and held passively against gravity without manual assistance. Participants were instructed to maintain the minimal force necessary to prevent the transducer from falling and to avoid contact with

their lips or tongue. After 30 seconds, participants were instructed to "let go," allowing the transducer to fall onto a pillow (placed on the lap in sitting; on a support surface in prone).

Each condition consisted of five 30-second trials. The first trial served as familiarisation and was excluded from analysis. The remaining four trials were averaged. A 30-second rest interval was provided between trials.

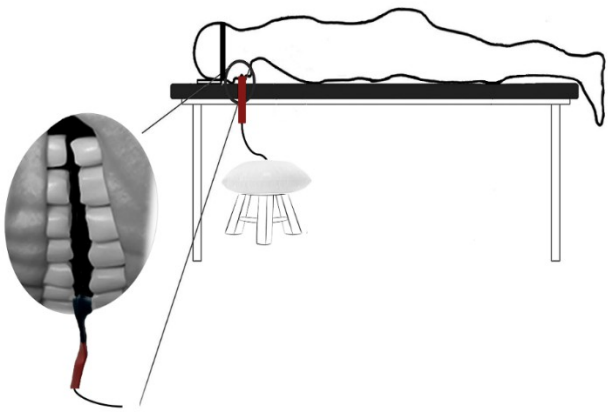

Figure 1: *The transducer was placed between the participant's upper and lower central incisors. Subjects were instructed to hold the transducer between their incisors with minimal force and to prevent it from falling. It was also emphasised that subjects should not touch the transducer with their lips or tongues. While sitting, subjects bent their heads forward so that the occlusal plane of their teeth was perpendicular to the ground. The same head position was also achieved during the lying prone position, as there was a large hole for the head on the examination bed.*

Body Positions

Sitting position: Participants were seated comfortably in a quiet room. The head was tilted forward so that the occlusal plane was perpendicular to the ground. A pillow was placed on the lap to protect the sensor if dropped.

Prone position: Participants lie on an examination table. The occlusal plane was again aligned perpendicular to the ground to maintain consistent gravitational loading across positions.

Local Anaesthesia

Local anaesthesia was administered by a single experienced dentist using articaine hydrochloride with epinephrine (80 mg/2 mL articaine + 0.02 mg/2 mL epinephrine; Maxicaine Fort, Vem Pharmaceuticals). Infiltration was performed bilaterally from canine to canine in both jaws (approximately 0.5 mL buccally and 0.1 mL palatally per tooth).

Successful anaesthesia was confirmed by subjective numbness and absence of response to light tactile stimulation and pressure testing. Experimental procedures were then repeated under anaesthetised conditions.

Clinical Periodontal Assessment

Periodontal status was classified according to the 2017 World Workshop Classification of Periodontal and Peri-Implant Diseases and Conditions. All measurements were performed by a single calibrated examiner using a UNC-15 periodontal probe (Hu-Friedy, Chicago, IL, USA). The following parameters were recorded at six sites per tooth:

- Clinical attachment level (CAL, mm)
- Bleeding on probing (BOP, %)
- Plaque index (PI)
- Gingival index (GI)

PI and GI were scored on established 0–3 scales (Löe and Silness, 1963; Silness and Löe, 1964). Full-mouth BOP was expressed as a percentage of bleeding sites. CAL was measured as the distance from the cemento-enamel junction to the base of the sulcus/pocket.

Data Processing and Statistical Analysis

For each condition, the mean of the four analysed trials was calculated. To enable inter-individual comparisons, minimum holding force values were normalised to each participant's maximal holding force across conditions and expressed as percentages.

Normality was assessed using the Shapiro–Wilk test. As percentage data were not normally distributed, pairwise comparisons were conducted using the Wilcoxon signed-rank test. Rank-based effect sizes were calculated for non-parametric comparisons.

Associations between holding force and periodontal parameters (CAL, BOP, PI, GI) were evaluated using linear regression models. Statistical significance was set at $\alpha = 0.05$.

RESULTS

Participant Characteristics

Twenty participants (12 females, 8 males; mean age ± SD: 23.2 ± 1.9 years) completed the study. All participants exhibited healthy periodontal status according to the 2017 World Workshop classification. Mean full-mouth clinical parameters were as follows: clinical

attachment level (CAL), 1.87 ± 0.17 mm; bleeding on probing (BOP), 23.19 ± 18.00%; plaque index (PI), 0.83 ± 0.44; and gingival index (GI), 0.71 ± 0.43. No participant reported discomfort during testing, and no adverse events occurred following local anaesthesia.

Table 1. *Minimum holding force values (N) of the participants*

	Minimum	Maximum	Mean ± SD
Sitting	0.05	1.86	0.63±0.63
LA-Sitting	0.03	9.40	1.87±2.26
Lying	0.08	6.50	1.23±1.49
LA-Lying	0.06	8.94	2.63±2.33

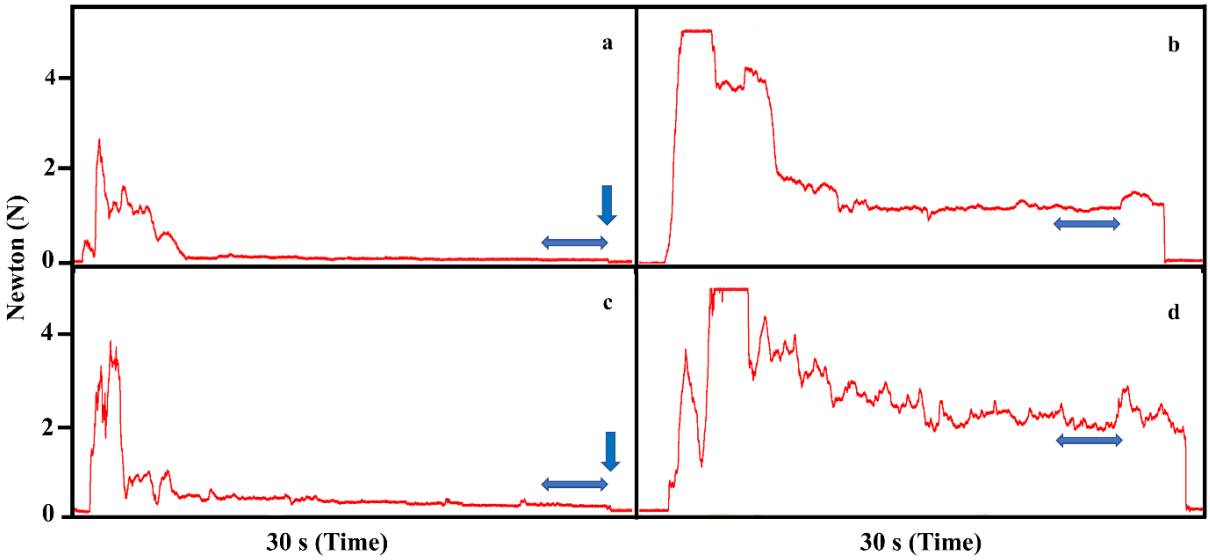

Figure 2: *An example of the holding force before and after local anaesthetic application.* ***a****. Holding force while sitting before local anaesthetic application,* ***b****. Holding force while sitting after local anaesthetic application,* ***c.*** *Holding force during lying before local anaesthetic application,* ***d.*** *Holding force during lying after local anaesthetic application. Note that when the subject first bites the transducer, the force trace increases dramatically and then settles to a steady level. Holding force for each trial was determined when it became steady, towards the end of the 30 s holding period, as shown by a horizontal double-headed arrow. This recording was obtained from Subject 11.*

Minimum Holding Force Across Experimental Conditions

Normalised minimum holding force values (expressed as a percentage of each participant's maximal value) differed significantly across experimental conditions. In the absence of local

anaesthesia, minimum holding force was significantly lower in the sitting position compared with the prone position (median [IQR]: 10.26 [5.29–31.70]% vs. 22.43 [13.09–48.71]%; p = 0.008; effect size r = 0.59).

Following local anaesthesia, minimum holding force increased significantly in both body positions compared with the corresponding non-anaesthetised conditions (sitting: p = 0.010; prone: p = 0.011). The magnitude of increase was 28.0% in the sitting condition and 36.1% in the prone condition.

Under anaesthetised conditions, the difference between sitting and prone positions was reduced and did not reach statistical significance (p = 0.073), suggesting attenuation of position-dependent modulation after sensory blockade.

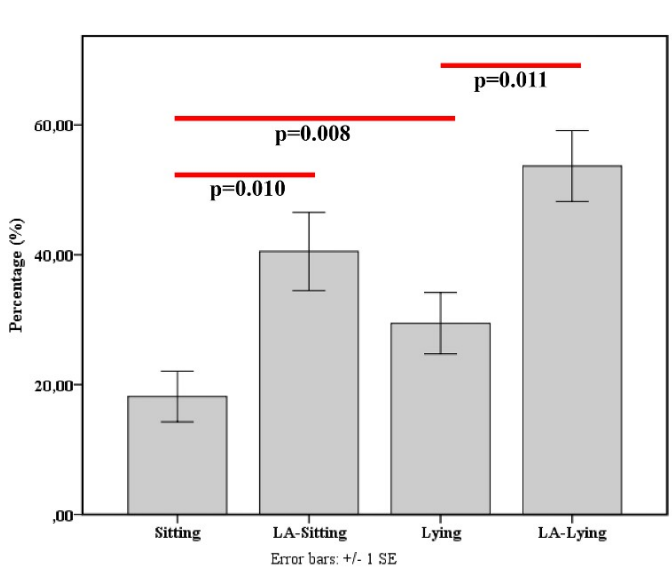

Figure 3: *Since there was an unprecedented variation of holding forces between individual subjects, we normalised values of each subject against his/her maximal holding force value. Pooling across subjects and obtaining proper means and standard errors thus became possible, as shown above. Data are presented as mean ± 1 standard error (SE). The LA application increased the holding force values in both positions. Significant differences were observed between sitting and LA-sitting (p = 0.010), sitting and lying (p = 0.008), and lying and LA-lying (p = 0.011).*

Effect Sizes

Rank-based effect sizes indicated a moderate-to-large effect of local anaesthesia on minimum holding force in both positions (r = 0.57–0.58), and a moderate effect of body position under non-anaesthetised conditions (r = 0.59).

Associations with Periodontal Parameters

Linear regression analyses revealed no significant associations between normalised minimum holding force and periodontal indices (CAL, BOP, PI, or GI) across conditions (all $P > 0.05$). Periodontal variables accounted for less than 24% of the variance in holding force.

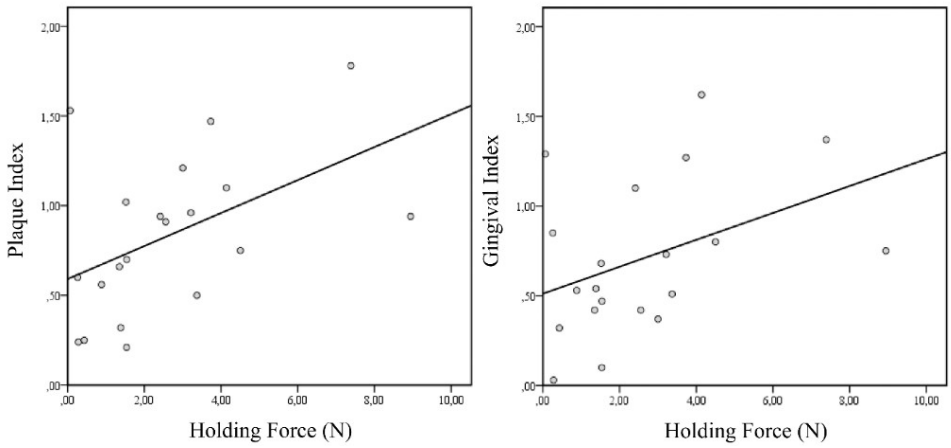

Figure 4. *Scatter plots illustrating the relationship between holding force (%) and periodontal indices (PI and GI) in the LA-lying condition. Each point represents one participant, and the solid line indicates the fitted linear regression model.*

Table 2: *Clinical measurements and holding force mean values (each value is an average of 4 measurements) in Newtons obtained from individuals are shown.*

Subject	Sitting without LA	Sitting with LA	Lying without LA	Lying with LA	PI	GI	CAL	BOP
1	.28	0.93	.87	1.54	0.21	0.10	1.59	1.39
2	1.51	1.05	3.20	3.37	0.50	0.51	1.92	16.67
3	.22	0.38	.18	.06	1.53	1.29	2.08	47.44
4	.07	0.43	.08	4.50	0.75	0.80	2.15	36.77
5	.05	0.29	.22	.26	0.60	0.85	1.81	39.70
6	.53	0.57	.73	1.38	0.32	0.54	1.77	17.86
7	1.47	2.89	1.27	.88	0.56	0.53	1.75	11.91
8	1.41	0.69	.69	1.35	0.66	0.42	2.09	17.16
9	1.86	3.51	2.42	7.39	1.78	1.37	2.13	58.20
10	.19	2.11	.44	2.56	0.91	0.42	1.98	9.43
11	.05	5.11	.41	2.41	0.94	1.10	2.00	35.12
12	.45	0.33	.46	.43	0.25	0.32	1.89	10.72
13	.11	0.90	.26	1.52	1.02	0.68	1.75	17.27
14	1.30	9.40	1.75	8.94	0.94	0.75	1.65	19.64
15	.31	2.80	.96	3.21	0.96	0.73	1.64	19.05
16	.45	3.63	.82	3.73	1.47	1.27	1.96	28.58

17	1.64	0.69	1.69	.28	0.24	0.03	1.77	0.60
18	.11	0.50	1.51	1.54	0.70	0.47	1.81	8.34
19	.07	1.23	6.50	3.00	1.21	0.37	1.76	5.36
20	.57	0.03	.24	4.14	1.10	1.62	1.96	62.50

Table 3: *Results of linear regression analyses between clinical periodontal parameters and holding force under different conditions. Values represent the coefficient of determination (R^2) and p-values obtained from linear regression analyses.*

	Sitting				**Lying**			
	Without LA		**With LA**		**Without LA**		**With LA**	
	R^2	**p**	**R^2**	**p**	**R^2**	**p**	**R^2**	**p**
PI	.002	.838	.091	.196	.024	.516	**.234**	**.031**
GI	.006	.746	.042	.386	.064	.284	.164	.076
CAL	.007	.731	.033	.446	.041	.390	.011	.657
BOP	.000	.989	.001	.874	.087	.207	.123	.129

LA: local anesthesia; PI: Plaque Index; GI: Gingival Index; CAL: Clinical Attachment Level; BOP: Bleeding on Probing. A linear regression model was used to obtain R^2 and p-values.

DISCUSSION

The present study demonstrates that periodontal sensory input plays a critical role in regulating low-level incisal holding force. Under physiological conditions, participants maintained stable object holding with remarkably low forces in both sitting (0.877 N) and prone (1.286 N) positions. Following local anaesthesia, minimum holding forces increased significantly in both positions (1.985 N and 2.524 N, respectively), indicating that the loss of periodontal afferent input results in a systematic overestimation of force.

These findings provide direct experimental support for the role of periodontal mechanoreceptors in fine-tuning oral motor output. Periodontal afferents are characterised by exceptionally high sensitivity to low-magnitude strain, particularly below 1 N in anterior teeth (Trulsson & Johansson, 2002; Trulsson, 2007). Their activity provides high-resolution feedback regarding tooth load direction, magnitude, and stability. When this feedback is pharmacologically blocked, the motor system appears to compensate by increasing force output to maintain object security, likely reflecting a safety-oriented control strategy in the absence of precise peripheral feedback. Our interpretation aligns with previous work demonstrating increased force levels and variability during experimental periodontal

deafferentation and in clinical conditions with reduced periodontal input (Johnsen et al., 2007; Svensson & Trulsson, 2009, 2011; Trulsson & Johansson, 1996b).

Importantly, the present results extend prior findings by demonstrating that the modulatory contribution of periodontal mechanoreceptors persists across different gravitational orientations. The minimum holding force was significantly higher in the prone position than in the sitting position under non-anaesthetised conditions. This positional effect may reflect biomechanical influences of head–neck alignment and gravitational loading on the dentoalveolar complex, potentially altering strain distribution or muscle recruitment patterns. However, the consistent increase in holding force following anaesthesia in both positions indicates that periodontal afferent input remains essential for low-force regulation irrespective of body orientation. Thus, periodontal feedback appears to provide a position-independent stabilising signal within the trigeminal sensorimotor system (Johnsen et al., 2007; Piancino et al., 2017; Svensson & Trulsson, 2009; Trulsson, 2006, 2007; Trulsson & Johansson, 1996a,b).

Inter-individual variability in holding force was substantial, whereas intra-individual variability remained relatively stable under intact sensory conditions. After anaesthesia, variability increased, suggesting reduced precision of motor output in the absence of periodontal feedback. Similar patterns of increased force variability have been reported in both experimental deafferentation paradigms and in individuals with implant-supported prostheses lacking periodontal receptors (Haraldson et al., 1979; Haraldson, 1983; Trulsson et al., 1996a,b). Collectively, these observations support the concept that periodontal mechanoreceptors contribute not only to force magnitude control but also to force stability and consistency.

Relationship Between Holding Force and Periodontal Status

An exploratory objective of this study was to examine associations between holding force and clinical periodontal indices. Under intact sensory conditions, no significant relationships were observed between minimum holding force and CAL, BOP, PI, or GI, suggesting that mild variations in periodontal or gingival status within a healthy population do not substantially alter functional periodontal afferent performance.

Interestingly, significant correlations between holding force and PI emerged only after local anaesthesia. This finding may indicate that when periodontal mechanoreceptor input is

eliminated, secondary sensorimotor mechanisms—such as muscle spindle afferents from the jaw and cervical musculature, or temporomandibular joint receptors—are insufficient to fully compensate for the loss of periodontal feedback. In other words, periodontal mechanoreceptors appear to provide a unique and non-redundant contribution to fine oral motor control. Although these findings should be interpreted cautiously, given the limited sample size, they suggest that periodontal proprioception may represent a distinct functional domain that is not easily replaced by other sensory systems.

Methodological Considerations

Several methodological features strengthen the present study. First, the lightweight, gravity-dependent transducer design minimised external stabilisation and reduced mechanical interference. Unlike handheld or manually stabilised sensor systems (Trulsson & Johansson, 2002), the current setup ensured that insufficient holding force resulted in immediate sensor displacement, thereby providing a functionally relevant measure of minimal force required to counteract gravity. This approach likely enhanced validity and measurement sensitivity.

Second, the force sensor operated within the physiologically relevant low-force range of periodontal mechanoreceptor sensitivity. Because periodontal afferents exhibit maximal responsiveness at low force levels, particularly in anterior teeth (Trulsson & Johansson, 2002; Trulsson, 2007), the high resolution of the measurement system allowed detection of subtle changes in force regulation before and during anaesthesia.

Third, a systematic comparison of the sitting and prone positions, controlled for potential gravitational and head–neck orientation effects that have not been consistently addressed in previous holding-force paradigms. By maintaining the occlusal plane perpendicular to the ground in both conditions, the design allowed controlled assessment of orientation-dependent modulation.

Finally, normalising force values to each participant's maximal condition reduced inter-individual scaling differences and enabled clearer identification of within-subject sensory effects. Notably, analyses using normalised values yielded different statistical patterns than raw force comparisons, underscoring the importance of accounting for individual motor scaling strategies.

Limitations

The study has several limitations. The sample size was modest and consisted exclusively of systemically and periodontally healthy adults, limiting generalizability to clinical populations. The experimental instruction to maintain "minimum force" inherently involves subjective interpretation, although the blindfolded design and gravity-dependent paradigm likely constrained behavioural variability. Additionally, only acute sensory blockade was examined; chronic sensory adaptation, as occurs in periodontal disease or implant rehabilitation, may produce different compensatory mechanisms.

Future studies should investigate larger and clinically diverse populations, including individuals with periodontitis, tooth loss, implant-supported prostheses, or temporomandibular disorders. Integration with electromyographic recordings and neurophysiological techniques would further elucidate the central mechanisms underlying periodontal-motor integration.

Conclusions

Within the limitations of this study, periodontal mechanoreceptors are essential for regulating low-level incisal holding force. Sensory blockade leads to systematic overproduction of holding force and increased variability, consistent with a compensatory motor strategy in the absence of high-resolution periodontal feedback. These findings reinforce the concept that periodontal afferents constitute a fundamental component of the trigeminal sensorimotor system, contributing uniquely to the precision and stability of oral motor control.

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