fortune Journals

FORTUNE JOURNAL OF HEALTH SCIENCES

ISSN: 2644-2906

Review Article

# Influence of Visual Input on Static Postural Equilibrium Differs According to Stability of Occlusal Contact State

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## Abstract

**Objectives:** This study aimed to elucidate the influence of visual input on static postural equilibrium, with a focus on the integration of occlusal factors.

**Methods:** Participants were 50 healthy men (18.6±1.4 years). To assess occlusal contact conditions, a pressure-sensitive sheet was used, categorizing participants into an occlusal stability group (n=26) and an occlusal instability group (n=24). Static postural equilibrium was measured using a center-of-gravity sway meter. Evaluation parameters were sway area (SA), sway path length per unit area (SPUA), and the Romberg ratio (RR). Measurements were performed at two jaw positions—mandibular rest position (MRP) and intercuspal position (ICP)—with the eyes both open and closed. The Friedman test, two-way repeated-measures ANOVA, and the Wilcoxon signed-rank test were used to analyze the three indices based on visual and occlusal conditions.

**Results:** Across both groups and occlusal conditions, SA was significantly smaller during the eyes-open state than the eyes-closed state. In the occlusal stability group with eyes open, ICP values were lower in the SA and higher in the SPUA ($P<0.01$). The occlusal stability group showed higher RR values in ICP ($P<0.01$).

**Conclusions:** This study revealed that static postural equilibrium exhibits a clear dependence on visual input, and this effect is fundamentally differentiated according to the stability of occlusal contact conditions. This implies that within a stable occlusal framework, occlusion not only facilitates postural orientation but also enhances visual responsiveness, thereby optimizing the overall mechanism of postural control.


**Keywords:** Static postural equilibrium; Visual input; Somatosensory input; occlusion; sway area; Sway path length per unit area; Romberg ratio

## Introduction

Postural control is primarily mediated by three distinct sensory inputs: visual, vestibular, and somatosensory [1–3]. Afferent information derived from these receptors is transmitted to the central nervous system, where it is integrated to modulate musculoskeletal activity across various bodily segments for the maintenance of postural equilibrium. Multiple intrinsic factors are known to modulate these sensory systems, and prior studies have documented the impact of occlusion, age, sex, height, and body weight on postural regulation and stability [4–6].

Postural equilibrium is categorized into dynamic and static components. Dynamic postural equilibrium entails the maintenance of bodily equilibrium against displacements of the center of mass caused by alterations in the base of support or posture, a process mediated by hierarchical reflexes or subconscious control [1–3]. In contrast, static postural equilibrium is highly susceptible to anatomical

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**Citation:** Mutsumi Takahashi, Yogetsu Bando, and Takuya Fukui. Influence of Visual Input on Static Postural Equilibrium Differs According to Stability of Occlusal Contact State. Fortune Journal of Health Sciences. 9 (2026): 483-489.

**Received:** August 20, 2026
**Accepted:** August 27, 2026
**Published:** August 31, 2026

structures and internal environmental factors. Studies of the stomatognathic region have addressed the relevance of occlusion; specifically, the experimental induction of occlusal interference via intraoral appliances increases center-of-pressure (COP) sway [4], whereas the improvement of occlusal contact through wearing a mouthguard suppresses COP displacement in trampolinists [5]. The deep sensations from the periodontal ligament and temporomandibular joint associated with occlusion and clenching belong to the somatosensory inputs [7,8]. Furthermore, the literature suggests that stimuli derived from occlusion and mastication potentially enhance the sensitivity of vestibular sensory inputs [9]. Specifically, it has been shown that the vestibular nucleus—the relay nucleus to which the vestibular nerve projects—receives not only information from the vestibular organs but also inputs regarding deep sensation of the neck and ocular movements. Stimuli to this region contribute to postural maintenance through their involvement in the vestibulo-ocular, vestibulocollic, and vestibulospinal reflexes. Additionally, extensive neural connections have been demonstrated, including somatosensory inputs from the stomatognathic region, trigeminal motor neurons innervating the masseter muscle, and the facial nucleus innervating the facial muscles. Collectively, these findings suggest that sensory inputs for postural control interact mutually, thereby inducing alterations in sensory integration and consequently modulating equilibrium regulation (i.e., postural equilibrium) as a motor output.

The objective of this study was to elucidate the influence of visual input on static postural equilibrium, with a focus on the integration of occlusal factors. The null hypothesis was that the impact of visual input on static postural equilibrium is not modulated by occlusal factors.

## Materials and Methods

### Participants

This study was conducted with the approval of the Ethics Committee of The Nippon Dental University School of Life Dentistry at Niigata (Approval No. ECNG-R-325). Prior to participation, the purpose and nature of the study were fully explained to all participants, and their informed consent was obtained.

Participants were 50 healthy men (mean age, 18.6±1.4 years) with no morphological or functional stomatognathic abnormalities participated. Exclusion criteria were current dental treatment or having missing teeth, with the exception of the third molars.

To assess occlusal contact conditions, a pressure-sensitive sheet (Dental Prescale, 50H-R; Fujifilm, Tokyo) and the dental analysis system (Occluzer, FPD-709; Fujifilm) were used [10–12]. Participants were instructed to perform

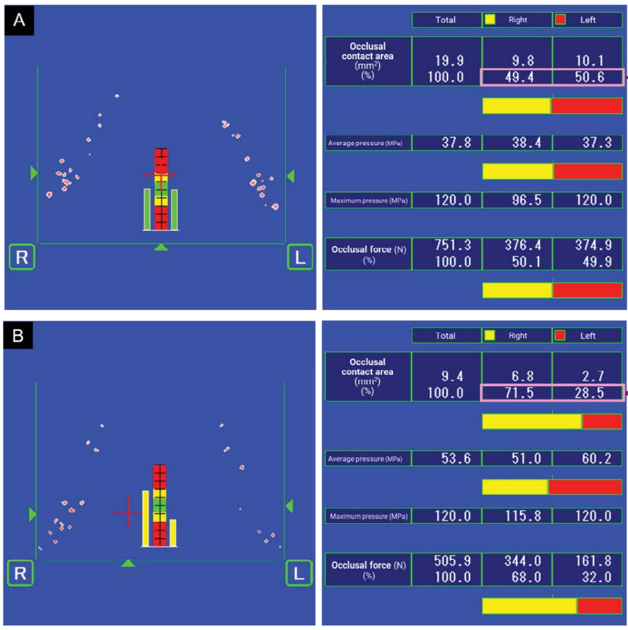


**Figure 1:** Analysis results of occlusal contact condition. The arrows indicate the left-right distribution of occlusal contact area (%). A: Occlusal stability group, B: Occlusal instability group.


**Figure 2:** Measurement of static postural stability using a center-of-gravity sway meter.

a 3-s maximal clenching task in the intercuspal position while seated with their occlusal plane parallel to the floor. Following the clenching task, the pressure-sensitive sheet was retrieved, and the bilateral percentage distribution of the occlusal contact area was determined via the dental analysis system. Based on previous criteria [12,13], participants with a bilateral discrepancy in the occlusal contact area of less than 10% were assigned to the occlusal stability group, and all other participants were assigned to the occlusal instability group (Figure 1). The resulting sample sizes were 26 and 24 participants, respectively.

### Measurement of static postural equilibrium

Static postural equilibrium was measured using a center-of-gravity sway meter (GRAVICORDER GS-7; Anima Co., Tokyo) [3,5,13], in accordance with the manufacturer's recommended protocol. Participants assumed an erect posture in a closed-stance position, with both medial foot margins touching and the centers of their soles aligned with the platform's reference point. Their gaze was directed at a target positioned at eye level 2 m ahead. Subsequently, the participants were instructed to relax and assume the mandibular rest position (MRP) without dental contact; recording was then performed for 30 s under the eyes-open condition. Following this, the participants were instructed to close their eyes. To allow for stabilization, recording under the eyes-closed condition was initiated approximately 20 s after the instruction and maintained for 30 s (Figure 2). Next, the participants were instructed to occlude in the intercuspal position (ICP) with occlusal contact, and 30-s recordings were performed under both eyes-open and eyes-closed conditions in an identical manner.

The evaluation parameters comprised the following three indices: the sway area (SA; the area enclosed by the COP trajectory) was used to quantify the magnitude of postural sway; the sway path length per unit area (SPUA) was used to reflect the fineness of postural control; and the Romberg ratio (RR) of the SA was used to evaluate the comparative impact of visual input on postural sway.

### Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics software (ver. 24.0; IBM Corp., Armonk, NY). Normality and homogeneity of variance were verified using the Shapiro–Wilk test and Levene's test, respectively. The Shapiro–Wilk test revealed that normality was rejected for SA across all levels in the occlusal stability group. For SPUA, normality was not observed at any level for the occlusal stability group, nor at the eyes-open with ICP level for the occlusal instability group. Similarly, RR lacked normality under the ICP condition of the occlusal stability group and the MRP condition of the occlusal instability group. In Levene's test, homogeneity of variance was satisfied only for SA in the occlusal instability group. Therefore, the Friedman test was employed to analyze SA and SPUA in the occlusal stability group and SPUA in the occlusal instability group, followed by the Bonferroni post-hoc adjustment for multiple comparisons upon detecting statistical significance. For SA in the occlusal instability group, two-way repeated-measures analysis of variance was performed, with subsequent significant factors isolated using paired *t*-tests. Differences in RR according to occlusal conditions within each group were evaluated using the Wilcoxon signed-rank test.

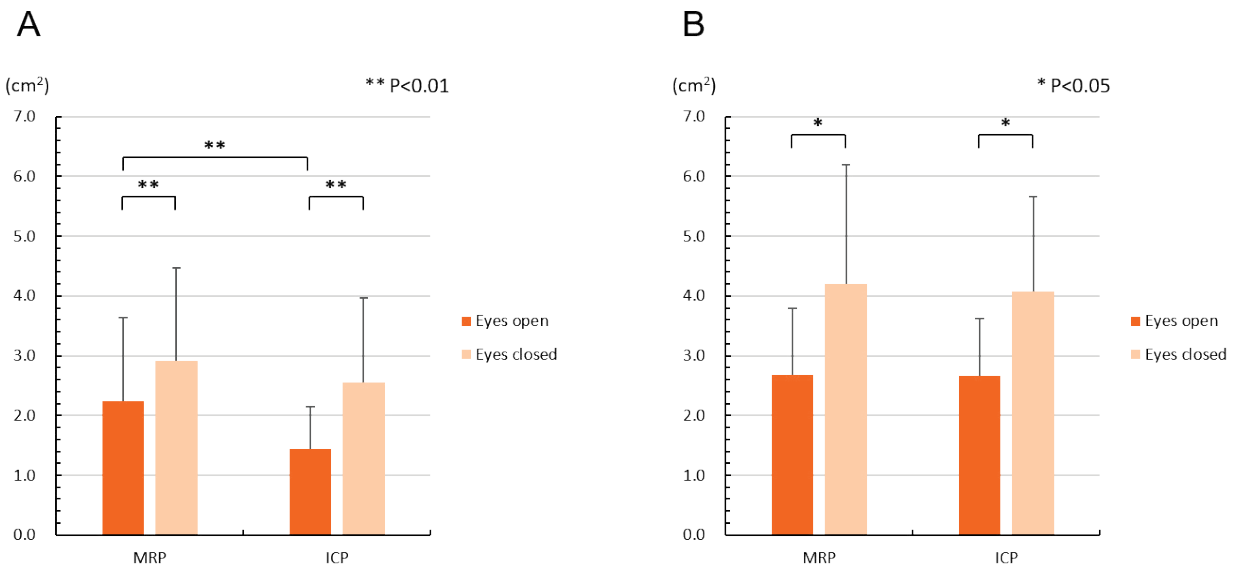


**Figure 3:** Differences in sway area (SA) due to visual and occlusal conditions. A: Occlusal stability group, B: Occlusal instability group.

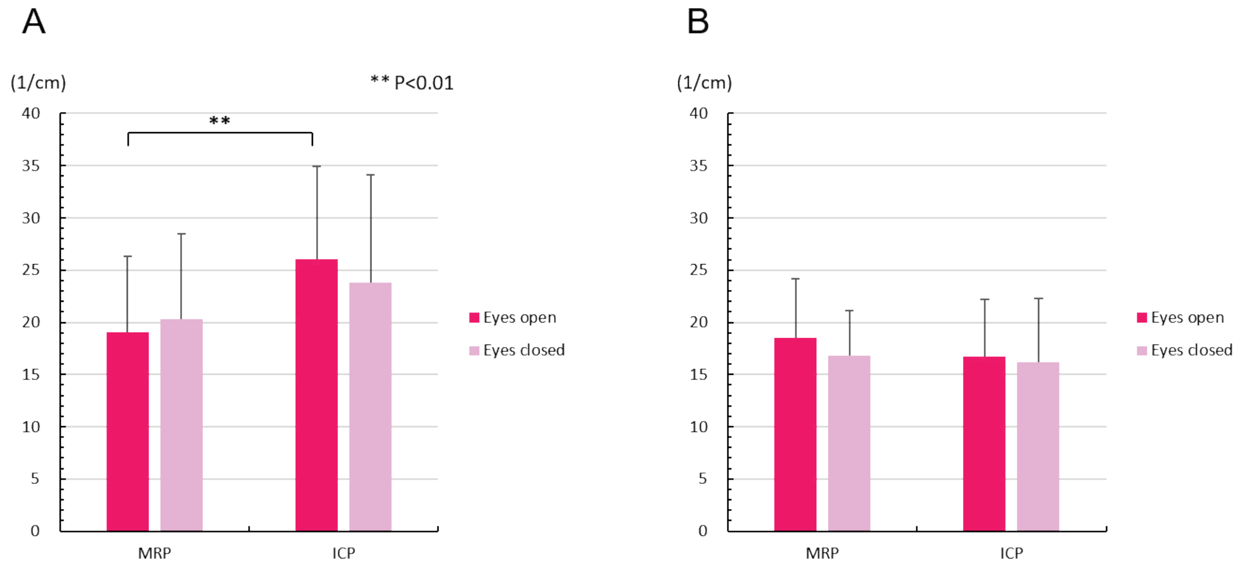


**Figure 4:** Differences in sway path length per unit area (SPUA) due to visual and occlusal conditions. A: Occlusal stability group, B: Occlusal instability group.

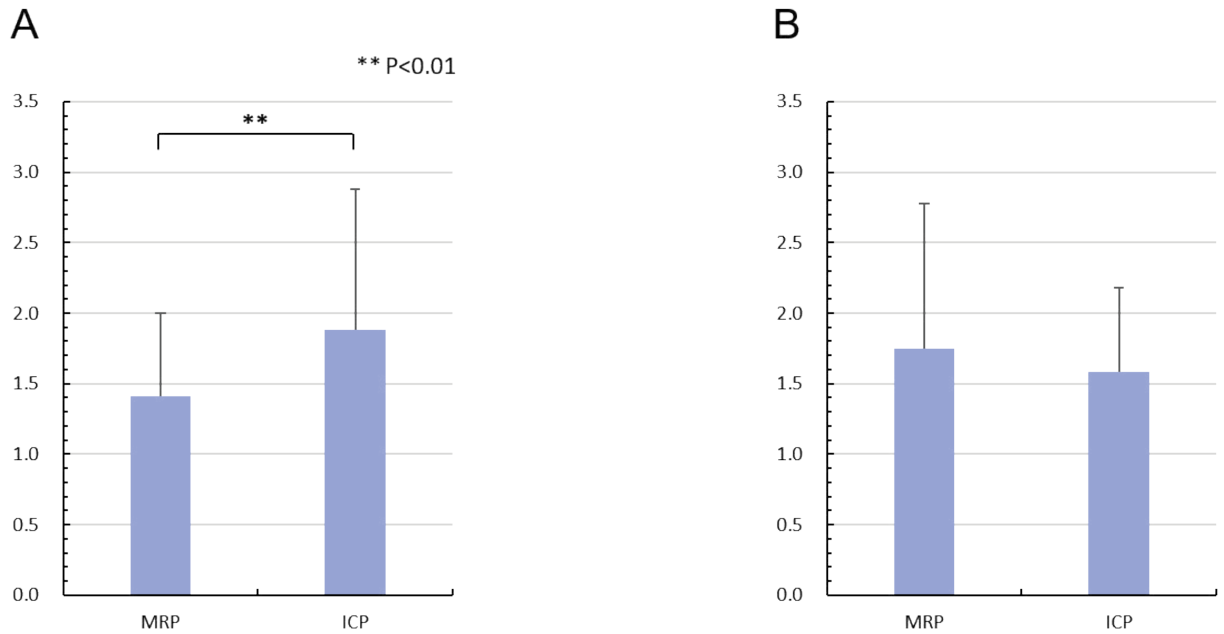


**Figure 5:** Comparison of Romberg ratios (RR) of sway area based on occlusal conditions. A: Occlusal stability group, B: Occlusal instability group.

## Results

Figure 3 shows the comparison of SA under different occlusal conditions during the eyes-open and eyes-closed conditions. Significant differences regarding visual conditions were observed in both the occlusal stability and instability groups; specifically, values obtained during the eyes-open state were significantly lower than those obtained during the eyes-closed state under both occlusal conditions. In contrast, significant differences associated with occlusal conditions were verified exclusively within the eyes-open condition of the occlusal stability group, where values in the ICP were significantly lower than those in the MRP (P<0.01).

Figure 4 shows the comparison of SPUA under different occlusal conditions during the eyes-open and eyes-closed

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DOI:10.26502/fjhs.440

conditions. No significant differences were observed regarding the visual conditions. However, significant differences associated with the occlusal conditions were verified exclusively within the eyes-open condition of the occlusal stability group, where values in the ICP were significantly higher than those in the MRP (P<0.01).

Significant differences in the RR associated with the occlusal conditions were verified exclusively within the occlusal stability group, where values in the ICP were significantly higher than those in the MRP (P<0.01) (Figure 5).

## Discussion

The results of this study revealed that the influence of visual input on static postural equilibrium varied according to the stability of the participants' occlusal contact status. Therefore, the null hypothesis was rejected.

In postural orientation, visual input serves as a critical source of information regarding head position and displacement by providing relative spatial data of surrounding objects. Consequently, its weight is greater than that of other sensory modalities, thereby attenuating COP sway, although its weight remains relatively low during the maintenance of a quiet standing posture [3,14]. In contrast, the priority of sensory inputs adapts dynamically to the characteristics of specific athletic disciplines, and their functional efficacy is manifest exclusively under conditions that match the training environment [15,16]. Furthermore, previous research has indicated that the level of contribution and the strategies for sensory integration vary significantly between professional and amateur athletes [17–19]. Given that a portion of the signals derived from visual, vestibular, and somatosensory receptors converges on the vestibular nucleus during their afferent projections to the central nervous system, it is hypothesized that stimuli from these three distinct sensory modalities mutually influence one another within the central processing pathway.

In this study, the impact of visual input on postural equilibrium was investigated by comparing the conditions with the eyes open and eyes closed. Consequently, SA—an index of postural sway magnitude—exhibited a clear dependence on visual input in both occlusal groups, with values significantly attenuated under the eyes-open condition compared with the eyes-closed condition. This implies that visual input inherently facilitates postural equilibrium even during minimal bodily displacement. In contrast, SPUA remained independent of visual conditions. It has been reported that SPUA quantifies the density of sway alterations within a constant spatial bound, thereby serving as an indicator of the precision of postural control and proprioceptive feedback mechanisms [20]. An elevated SPUA signifies that fine-grained postural corrections occur frequently within a confined boundary. Because SA expanded significantly when the eyes were closed, the absence of a significant change in SPUA implies a proportional, concomitant increase in both total locus length and SA, neutralizing any statistical variance in this specific parameter.

Previous research has suggested that sensory input thresholds triggered by postural sway are velocity-dependent, with proprioception exhibiting the lowest threshold during static or low-velocity sway [21]. The experimental protocol involved two occlusal states: the MRP and the ICP. The MRP represents the resting jaw position assumed when sitting upright in a relaxed state, which is defined by a lack of interdental contact and minimal physiological strain on the craniocervical musculature [22,23]. In contrast, the ICP is characterized by the maximum contact area between the upper and lower arches, achieving optimal intercuspation [24,25]. Regarding masticatory electromyographic dynamics, the jaw-closing muscles in the MRP exhibit only baseline continuous tonus—an involuntary, low-level tonic contraction—that alleviates stress on the craniometrical complex [22,26,27]. In contrast, the ICP amplifies jaw-closing muscle activity via dental contact, and factors such as occlusal interference can easily induce asymmetric or excessive loading on specific muscle bellies [28,29]. This implies that maintaining the ICP generates robust afferent signals from mechanoreceptors within the masticatory muscles, temporomandibular joints, and periodontal ligaments. These signals project centrally as somatosensory feedback to modulate postural control. Consequently, this enhanced sensory feedback likely explains why the occlusal stability group exhibited a reduced SA in the ICP condition, as shown in Figure 3. Because a reduction in SA mathematically elevates SPUA under an identical regulatory framework, SPUA was inherently augmented under the ICP condition within the occlusal stability group, as confirmed in Figure 4.

Previous studies have reported that occlusion closely interacts with craniocervical proprioception and the vestibular network via the temporomandibular joints and masticatory musculature to modulate postural control [30–32]. In the occlusal stability group, afferent feedback from the periodontal ligaments and masticatory muscles during intercuspation provided a reliable reference frame for postural adjustment. When this feedback is combined with visual inputs, it presumably drives a more robust multisensory integration process, ultimately multiplying fine-grained postural corrections within a constant spatial bound and elevating SPUA. Moreover, in an optimal state, occlusion likely optimizes symmetrical and efficient masticatory muscle dynamics. This enhancement stems from the light muscular activation facilitating micro-adjustments, alongside idealized craniometrical alignment that constrains macroscopic bodily displacement. In contrast, the occlusal instability group potentially harbored bilateral asymmetries, including unbalanced muscle activity and jaw orientation during occlusion. Consequently, occlusion failed to function as a stabilizing anchor; rather, asymmetric masticatory activity disrupted fine-grained motor control, acting instead as a mechanical or neural perturbation. This suggests that while somatosensory feedback facilitates postural equilibrium as long as the contact status is stable, an unstable contact configuration neutralizes any positive sensory contribution. The absence of significant variance between occlusal conditions within the instability group might stem from our protocol being restricted to static assessments. Furthermore, our strict exclusion criteria—barring individuals with structural or functional stomatognathic pathologies, ongoing dental interventions, or missing teeth (except third molars)—likely minimized bias in the measurements. In clinical phenotypes where occlusion introduces explicit internal perturbation, including missing dentition, premature contacts, or severe malocclusion, intercuspation might inherently serve as a destabilizing factor for postural equilibrium.

Regarding the RR, a significant variance dependent on occlusal conditions was detected only within the occlusal stability group, indicating that the impact of visual function was more pronounced in the ICP. This implies that within a regulatory framework in which occlusion acts as a stable spatial reference for postural orientation, the integration of this somatosensory feedback inherently enhances the efficacy of visual inputs for postural stabilization. In contrast, the lack of significant differences in the RR across occlusal states in the instability group reinforces the concept that the cross-modal contribution of visual input to postural control is fundamentally modulated by whether the occlusal status provides a stabilizing reference or introduces internal perturbation.

The primary limitation of the present study is that it did not include participants with severe malocclusion, such as those exhibiting premature contacts, tooth loss, or dental crowding. Investigating the impact of occlusion on postural equilibrium by including these specific populations would facilitate a comprehensive analysis of postural regulation patterns in scenarios where somatosensory input acts as a disturbing factor or perturbation. Therefore, future research needs to expand the categories of participants to thoroughly investigate how each distinct sensory input affects postural adjustment.

## Conclusions

This study revealed that static postural equilibrium exhibits a clear dependence on visual input, and this effect is fundamentally differentiated according to the stability of occlusal contact conditions. This implies that within a stable occlusal framework, occlusion not only facilitates postural orientation but also enhances visual responsiveness, thereby optimizing the overall mechanism of postural control.

**Funding:** This work was supported by JSPS KAKENHI Grant Number JP23K10617.

**Institutional Review Board Statement:** Ethics Committee of The Nippon Dental University School of Life Dentistry at Niigata (Approval No. ECNG-R-325).

**Data Availability Statement:** The data underlying this article will be shared on reasonable request to the corresponding author.

**Conflicts of interest statement:** The authors have no conflicts of interest relevant to this article.

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