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Verification of Relationship between Static and Dynamic Balance Using Cross Test Trajectory Diagram as Indicator

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Abstract

Purpose: The aim of this study was to clarify the relationship between static and dynamic balance using the cross-test trajectory diagram as an index. Method: The participants were 14 male trampoline gymnasts. Center-of-gravity sway meter was used to measure balance ability. Static balance was recorded in the following conditions: mandibular resting position (RP), intercuspal position (Cl), and mouthguard worn (MG-Cl), and the outer circumferential area (ENV-area) and unit area trajectory length (LNG/E-area) were recorded. Dynamic balance was evaluated using the R/E-value calculated by the cross-test. In addition to static balance, two conditions were measured without clenching instructions: without mouthguard (Fr) and with mouthguard (MG-Fr). Differences in ENV-area or LNG/E-area due to occlusal conditions were analyzed using the Friedmann test. Differences in the R/E value due to occlusal conditions were compared using repeated measures analysis of variance. Correlation analyses between static and dynamic balance were performed in RP, Cl, and MG-Cl using Pearson's product moment correlation coefficient or Spearman's rank correlation coefficient. Results: For MG-Cl, ENV-area had the lowest value, while LNG/E-area and R/E-value were the highest. In RP or MG-Cl, a negative correlation was observed between ENV-area and R/E-value and a positive correlation between LNG/E-area and R/E-value ($P < 0.05$). Conclusion: This study clarified that the relationship between static and dynamic balance was observed in mandibular resting position and mouthguard worn. Therefore, the R/E-value reflects static balance, suggesting that the center of gravity can be moved efficiently in an internal environment with stable static balance.

Keywords

Static Balance, Dynamic Balance, Cross-Test, Occlusion, Center-of-Gravity Trajectory Diagram

1. Introduction

Postural stability is achieved through antigravity muscle activity and postural reflexes (Ghamkhar & Kahlaee, 2019), and can be divided into static balance, which maintains a resting posture, and dynamic balance, which responds to changes in the base of support or center of gravity (Nagano, 2023). Common methods for assessing static balance include the one-leg standing test, the Short Physical Performance Battery, and the Romberg test, which are evaluated based on posture maintenance time and center of foot pressure (COP) displacement. In these methods, differences due to age, sex, weight, etc. have been reported (Asseman et al., 2008; Bando, 2019a, 2019b; Engler et al., 2011; Hirano et al., 2021; Itaya, 2015; Marini et al., 2013; Welch et al., 2021). Evaluation methods for dynamic balance include the cross test, functional reach test, timed up-and-go test, and four-square step test (Aquino et al., 2022; Engler et al., 2011; Fukuyama & Maruyama, 2010; Hirano et al., 2021; Moore & Barker, 2017). These methods are selected depending on the subject's health condition, age, disease, or in the case of athletes, the characteristics of the sport.

Focusing on the physical abilities of athletes, we previously investigated the effects of occlusion on postural control functions and athletic abilities (Takahashi et al., 2023a, 2023b, 2023c); we found that the influence of the occlusal contact state on static balance varies depending on the type of competition and that correcting the occlusal contact state by wearing an intraoral appliance improves static balance. We also found that occlusal force and occlusal contact state affect agility and muscle strength in physical fitness tests (Takahashi & Bando, 2018; Takahashi et al., 2023d). Other studies have reported that professional athletes have smaller COP displacements compared with amateur athletes (Paillard & Noé, 2006) and that specialized training specific to the sport influences the priority of sensory input in postural control (Asseman et al., 2008).

At present, there is no consensus regarding the relationship between static balance and dynamic balance, which is due in part to the variety of evaluation methods and the different characteristics depending on the target (Jonsson et al., 2003; Fukuyama & Maruyama, 2010). In the present study, we targeted trampoline gymnasts, for whom posture training is critical, as participants.

The purpose of this study was to clarify the influence of occlusal conditions on the relationship between static balance and dynamic balance using cross test trajectory analysis as an index. The null hypothesis was that there is no relationship between static balance and dynamic balance, and that there are no differences due to occlusal conditions.

2. Materials and Methods

2.1. Ethical Approval of Studies and Informed Consent

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-443). The details of the study were fully explained to all participants, and written informed consent was obtained from all participants prior to participation.

2.2. Participants

The participants were 14 male trampoline athletes (mean age; 18.1 ± 2.1 years) with no subjective or objective morphological or functional abnormalities in the stomatognathic system. Those with missing teeth other than third molars and those undergoing dental treatment were excluded. The mean competitive experience was 12.1 ± 2.6 years.

2.3. Fabrication of Mouthguard

Impressions of each participant's upper jaw were taken using alginate impression material (Aroma fine plus normal set, GC Co., Tokyo, Japan) and impression trays (Disposable trays, GC Co.). Dental hard plaster (New Plastone; GC Co.) was injected into the impression body to create a working model. The plaster model was trimmed so that the basal surface was horizontal and there was no undercut on the labial side. After thoroughly drying the working model, molding operations were performed as specified by the manufacturer. The mouthguard was fabricated using a 2.0-mm thick ethylene vinyl acetate thermoplastic elastomer (Sports Mouthguard; Keystone Industries, Cherry Hill, NJ) and a pressure molding machine (Model Capture Try; Shofu Inc., Kyoto, Japan). After the molded body was allowed to cool to room temperature, the excess portion was removed and the edges were polished. A mouthguard was placed in the participant's mouth, and the bite was adjusted so that all teeth were in even contact when lightly clenching (Bando et al., 2019b; Takahashi et al., 2023a, 2023d). The occlusal contact state of the mouthguard was confirmed by occlusal examination using blue silicone (Bite Eye; GC Co.) (Takahashi et al., 2023d).

2.4. Measurement of Static Balance

Static balance was measured using a center of gravity sway meter (GRAVICORDER GS-7; Anima, Tokyo, Japan). The measurements were performed in accordance with the manufacturer's recommended method, and the outer circumferential area (ENV-area) and unit area trajectory length (LNG/E-area) were recorded (Itaya, 2015; Bando et al., 2019a, 2019b; Takahashi et al., 2023a). A dentist with experience operating the center-of-gravity sway meter instructed the participants and then performed measurements in a quiet, evenly lit environment to avoid body deviation due to visual and auditory stimulation. The participants were instructed to stand upright with their feet closed so that the center of their soles matched the reference point on the measuring table, with their medial sides touching, and in a natural standing position with both upper limbs touching the sides of their bodies. Participants were instructed to focus their gaze on a target object 2 m in front of them at eye level. The measurement conditions were the mandibular resting position (RP), clenching or occlusion in the intercuspal position (Cl), and clenching or occlusion with the mouthguard worn (MG-Cl). After confirming that the standing posture was stable, recording was started. The time for one measurement was 30 s.

2.5. Measurement of Dynamic Balance

Dynamic balance was evaluated by the cross test, using a center-of-gravity sway meter (GRAVICORDER GS-7; Anima). Participants were asked to stand upright with the inner sides of their feet 5 cm from the reference point on the measuring table, and in a natural standing position with both upper limbs touching the sides of their bodies. Participants were instructed to focus their gaze on a target object 2 m in front of them at eye level. For measurements, participants were instructed to move their upper bodies every 3 s in the following order: forward, standard position, backward, standard position, left, standard position, right, standard position, with the standard position being a static standing position. During the measurement, participants were instructed to not let the soles of their feet leave the measurement table (Fukuyama & Maruyama, 2010). In addition to the three conditions of static balance (RP, Cl, and MG-Cl), the measurement conditions included a condition in which a mouthguard was worn (MG-Fr) and a condition in which it was not (Fr), with the participants allowed to freely clench and occlude during the measurement. The measurement time for each condition was 30 s. The index of dynamic balance was the rectangular area (REC-area) obtained from the product of the COP movement distance in the longitudinal and lateral directions of the center-of-gravity trajectory diagram divided by the ENV-area (R/E value) (Fukuyama & Maruyama, 2010).

2.6. Statistical Analysis

Statistical analysis was performed using SPSS 17.0 software (SPSS Japan Inc., Tokyo, Japan) and the level of significance was set at $P < 0.05$. The Shapiro-Wilk test was used for normality testing. Normality was confirmed at each level except for ENV-area and LNG/E-area of the RP condition.

Differences in ENV-area or LNG/E-area due to occlusal conditions were analyzed using the Friedmann test. Differences in the R/E value due to occlusal conditions were compared using repeated measures analysis of variance, and the results of Mauchly's sphericity test ensured homogeneity of variance. After these tests, multiple comparison tests between levels were performed using the Bonferroni method.

To examine the relationship between static balance and dynamic balance, the correlation between ENV-area or LNG/E-area and R/E value under three occlusal conditions (i.e., RP, Cl, and MG-Cl) were analyzed using Pearson's product moment correlation coefficient or Spearman's rank correlation coefficient.

3. Results

Figure 1 shows an example of the measurement results of static balance and dynamic balance. Regarding the static center of gravity, the smaller the COP displacement, the smaller the longitudinal and lateral displacements, and as a result, the ENV-area shows a lower value. The LNG/E-area was used to evaluate the speed of returning the COP displacement to the center position. As with the results of the static center-of-gravity measurement, the results of the cross-tested dynamic center-of-gravity sway include COP longitudinal displacement, COP lateral displacement, ENV-area, and LNG/E-area. The distances in the longitudinal and lateral directions of the center-of-gravity trajectory diagram were measured, and the product of both (REC-area) was calculated. The R/E value was calculated by dividing REC-area by ENV-area.

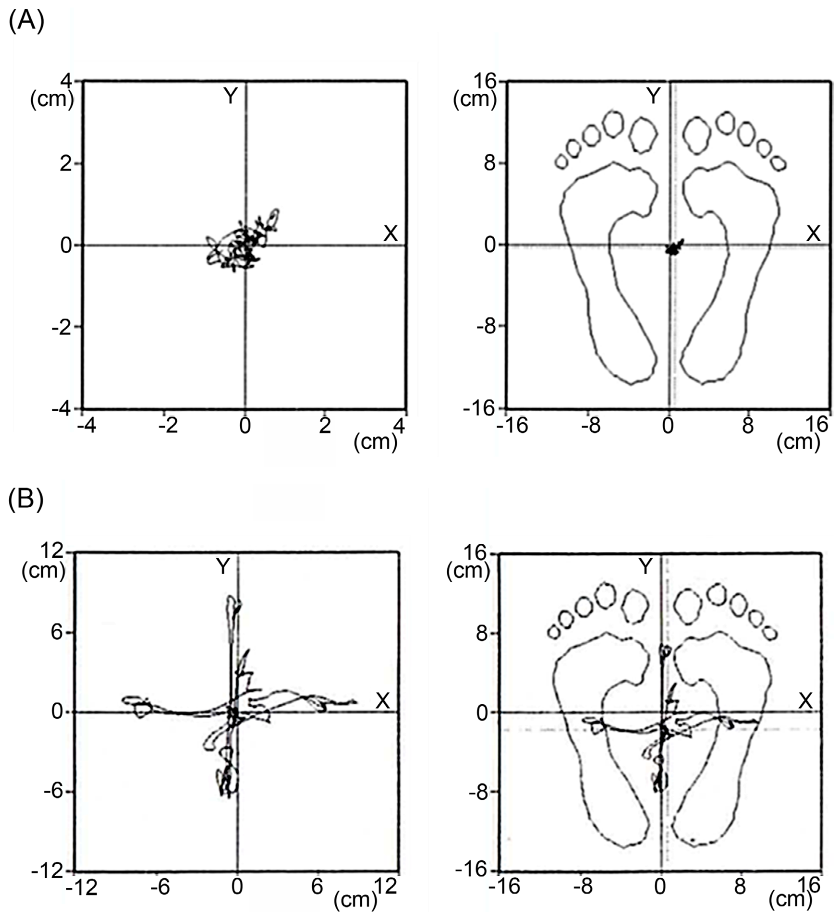

Figure 1. Examples of static and dynamic balance measurement results. (A): Center-of-gravity trajectory diagram during static balance measurement, (B): Center-of-gravity trajectory diagram during dynamic balance measurement.

Figure 2(A) shows the results of a multiple comparison test analyzing the difference in ENV-area depending on occlusal conditions. The measured values decreased in the order of RP, Cl, and MG-Cl, and a significant difference was observed between RP and MG-Cl ($P < 0.01$).

Figure 2(B) shows the results of a multiple comparison test analyzing the difference in LNG/E-area depending on occlusal conditions. The measured values increased in the order of RP, Cl, and MG-Cl, and significant differences were observed between RP and MG-Cl (P < 0.01) and between Cl and MG-Cl (P < 0.05).

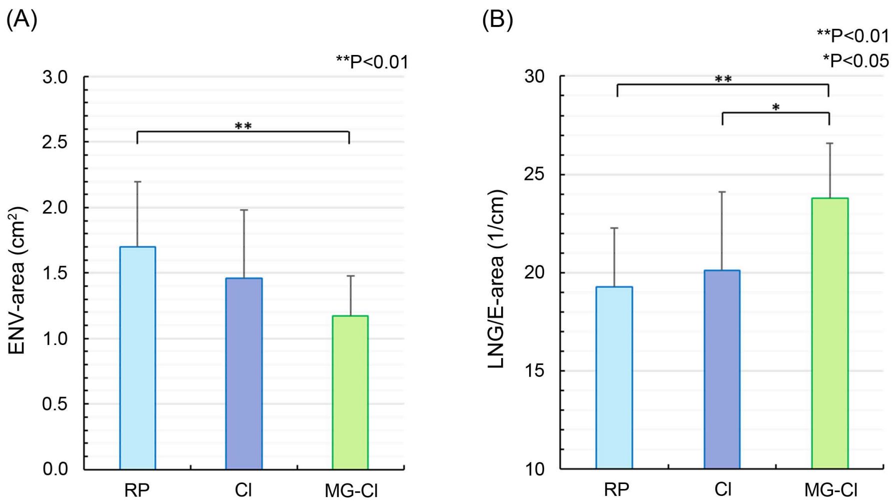

Figure 2. Results of multiple comparison tests on differences in static balance due to occlusal conditions. (A): ENV-area, (B): LNG/E-area. Measurements are expressed as means + SD. Error bar indicates standard error of the mean. **P < 0.01, *P < 0.05: denotes statistically significant difference.

Figure 3 shows the results of a multiple comparison test analyzing the differences in R/E value depending on occlusal conditions. MG-Cl and MG-Fr conditions showed higher values than RP, Cl, and Fr, and there were significant differences between Cl and MG-Cl (P < 0.05), Cl and MG-Fr (P < 0.05), Fr and MG-Cl (P < 0.05), and Fr and MG-Fr (P < 0.05).

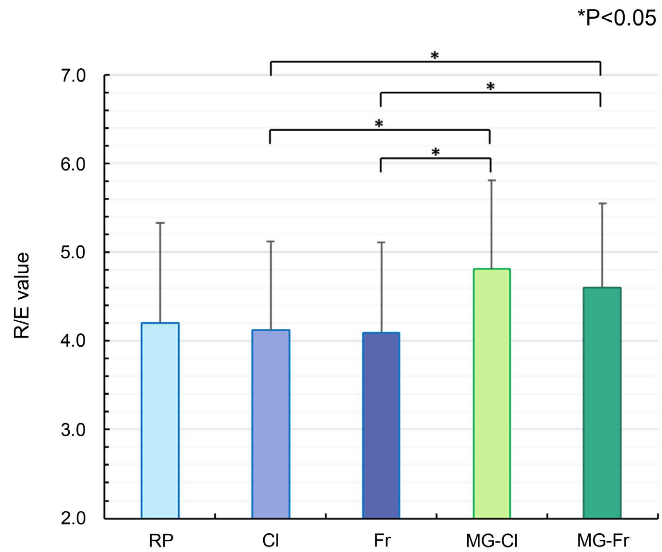

Figure 3. Results of multiple comparison test on differences in R/E value due to occlusal conditions. Measurements are expressed as means + SD. Error bar indicates standard error of the mean. *P < 0.05: denotes statistically significant difference.

Figure 4 shows the correlation analysis results for ENV-area and R/E value depending on occlusal conditions. Under all conditions, the R/E value tended to decrease as ENV-area increased. A negative correlation was observed between ENV-area and R/E value in RP ($R = -0.554$, $P < 0.05$) or in MG-Cl ($R = -0.577$, $P < 0.05$). Under Cl, no significant correlation was observed between ENV-area and R/E values ($R = -0.413$, $P = 0.142$).

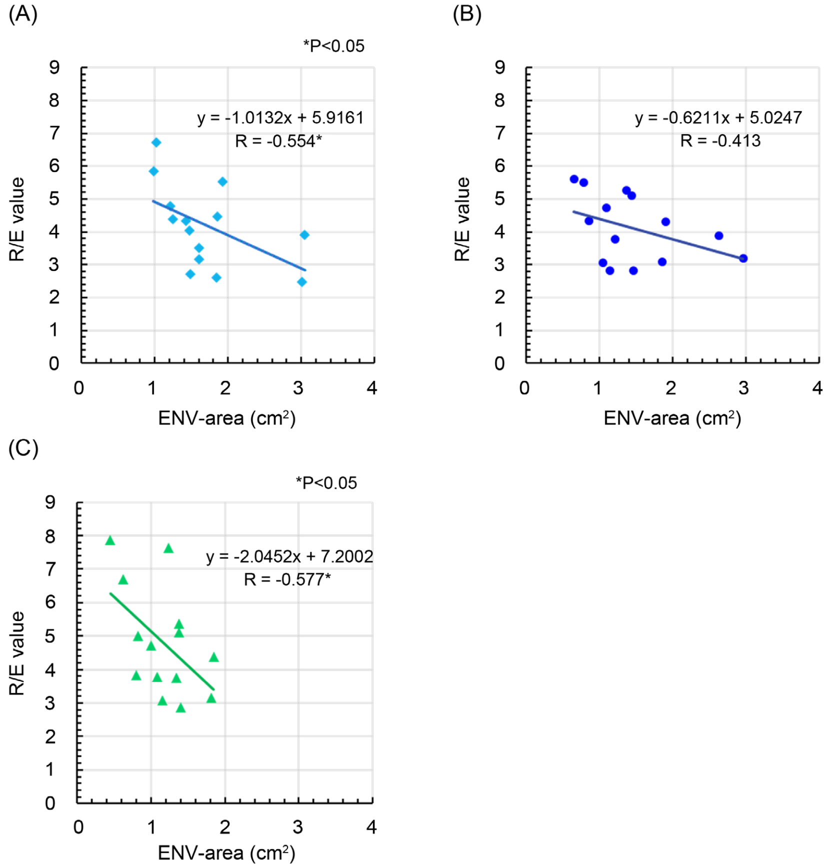

Figure 4. Results of correlation analysis between ENV-area and R/E value depending on occlusal conditions. (A): RP, mandibular resting position, (B): Cl, clenching or occlusion in the intercuspal position, (C): MG-Cl, clenching or occlusion with the mouthguard worn. *$P < 0.05$: denotes statistically significant difference.

Figure 5 shows the correlation analysis results for LNG/E-area and R/E value depending on occlusal conditions. Under all conditions, the R/E value tended to increase as LNG/E-area increased. A positive correlation was observed between LNG/E-area and R/E value in RP ($R = 0.528$, $P < 0.05$) or in MG-Cl ($R = 0.533$, $P < 0.05$). Under Cl, no significant correlation was observed between LNG/E-area and R/E value ($R = 0.450$, $P = 0.107$).

4. Discussion

The analyses performed in this study revealed a relationship between static balance and dynamic balance when the mandible was in the resting position and a mouthguard was worn; therefore, the null hypothesis was rejected.

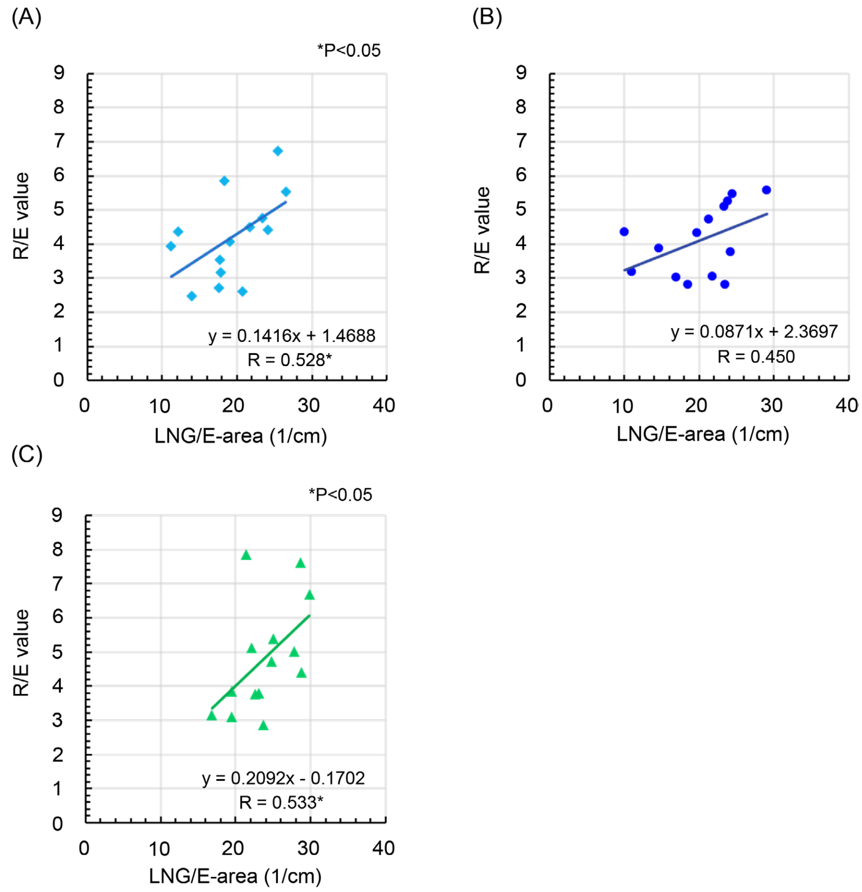

Figure 5. Results of correlation analysis between LNG/E-area and R/E value depending on occlusal conditions. (A): RP, mandibular resting position, (B): Cl, clenching or occlusion in the intercuspal position, (C): MG-Cl, clenching or occlusion with the mouthguard worn. *P < 0.05: denotes statistically significant difference.

There are two main reasons why we targeted trampoline gymnasts in this study. First, previous research has confirmed that competitive athletes who engage primarily in postural training have higher postural stability compared with athletes who primarily engage in strength training, and that the effects of intervention tend to be more pronounced (Takahashi et al., 2023a). Second, in trampoline competitions, postural adjustment made by the athlete while in the air directly affects performance ability, and it was surmised that the results of this research could be applied in the training and development of athletes.

Interventions targeting occlusion, which affects the sensory input of postural adjustment (Marini et al., 2013; Bando et al., 2019b), can easily be performed using intraoral appliances. Moreover, it is possible to improve occlusal contact without causing any burden to participants. It has been well established that occlusal correction using a mouthguard improves postural control function and affects motor function (Bando et al., 2019a, 2019b; Takahashi et al., 2023a, 2023b, 2023c, 2023d). Postural stability in athletes is expected to affect both anticipatory and reactive postural control, and therefore performance. Therefore, in the present study, a mouthguard was used to correct occlusion in the participants.

Three occlusal conditions were selected for static balance measurement: RP, Cl, and MG-Cl. This was done to compare differences resulting from the presence or absence of occlusal contact (i.e., between RP and Cl) as well as differences resulting from the balance of the occlusal contact state (i.e., between Cl and MG-Cl). Meanwhile, in the measurement of dynamic balance, conditions were added in which instructions for clenching or tooth contact were not given. This is because in the preliminary experiment, we observed that many participants temporarily clenched their teeth when moving their upper bodies, a phenomenon that was confirmed in the post-measurement questionnaire survey. In general, clenching may occur when exerting muscle strength or during movements that require stability of the trunk in order to control posture by using the internal environment (Takahashi et al., 2023d). For this reason, Fr and MG-Fr were added as occlusal conditions for dynamic balance.

Although there are multiple methods for evaluating dynamic balance, this study adopted the cross test (Fukuyama & Maruyama, 2010). The ENV-area and REC-area obtained by the cross test depended on the degree of each participant's upper body movement, so it was difficult to determine whether their dynamic balance was good or poor. Furthermore, because the task was to move the COP within a certain period of time, it was difficult to evaluate balance ability from LNG/E-area, which is an indicator of recovery speed. A cross-test trajectory diagram showed that the better the dynamic balance, the clearer the cross; given that the R/E value has been reported as an index that quantifies this, it is expected to be true when the REC-area is the same (Fukuyama & Maruyama, 2010). For this reason, in this study, we decided to use the R/E value as an index of dynamic balance and evaluate its relationship with static balance.

Under the occlusal conditions of this study, ENV-area was smallest and the LNG/E-area was largest under MG-Cl, demonstrating the best static balance. The results of this study, in which occlusal correction with a mouthguard improved the ability to control static standing posture, were in line with previous studies (Bando et al., 2019a, 2019b; Takahashi et al., 2023a). To compare the R/E value as an index of dynamic balance, it is assumed that the REC-area is the same. For this reason, repeated measures analysis of variance was performed after confirming the normality of each level among the five occlusal conditions; however, the results did not show any significant difference. In this study, the R/E value was significantly higher for MG-Cl and MG-Fr than for Cl and Fr. Therefore, except for the mandibular resting condition, there was a clearer center-of-gravity trajectory when wearing a mouthguard than when not wearing one, and the dynamic balance was better. Among these four conditions, the R/E value was higher when the mouthguard was worn than when it was not, likely because momentary clenching or occlusal contact stabilized the trunk when the center of gravity shifted. In other words, under measurement conditions where clenching or tooth contact occurs, it is possible that the stable occlusal state corrected by the mouthguard had a beneficial effect on postural control.

A significant correlation was observed between static balance and dynamic balance in RP and MG-Cl, suggesting that the R/E value and center-of-gravity trajectory diagram reflected static balance. This further suggests that in an internal environment with good static balance, it may be possible to move the center of gravity efficiently. When the distribution of the occlusal contact area of the participants in this study was confirmed in advance using a pressure-sensitive film (Dental Prescale), the average difference between the left and right sides of the occlusal contact area was approximately 16.2%. In other words, the participants in this study were a group with unbalanced occlusal contact conditions. Based on these findings, it is possible that occlusal contact became a disturbance factor for postural stability under Cl. A correlation was observed between static balance and dynamic balance when a mouthguard was worn for the purpose of occlusal correction; therefore, balance ability measured with clenched teeth or teeth in contact was considered to be beneficial for postural stability if the participant's occlusal contact was balanced, and to be a disturbance factor if it was unbalanced.

From the above, the possibility of providing visual and objective feedback on balance ability by using the R/E value was suggested, although it is not possible to objectively evaluate the cross test based on the clarity of the center-of-gravity trajectory diagram alone. When measuring COP displacement, the presence of disturbing factors directly affects the measurement results. Therefore, when performing measurements, it is necessary to keep in mind that the measurement conditions might affect the relationship between static balance and dynamic balance as well as the reliability of the R/E value. In other words, measurement when the mandible is in the resting position may be a useful measurement condition for many participants. In addition, by comparing the measured values in the mandibular resting position and in the clenched or occlusal state, it might be possible to infer whether the participant's occlusal contact is a disturbance factor. The index of balance ability using the R/E value can be used for interventions aimed at improving the physical strengthening of athletes and might also be useful for evaluating the balance ability of patients and the elderly. In addition, the findings from this study can serve as a basis for raising awareness about the importance of occlusal treatment and oral health management in preventing falls, improving quality of life, preventing and reducing sports injuries, and improving sports competitiveness among the elderly. Alternatively, when playing sports, it is recommended to use intraoral appliances not only for the purpose of mitigating impact forces but also for improving postural stability through occlusal correction. In a future study, we intend to clarify the differences between trampoline athletes and those in other sports, and the differences in dynamic balance assessment methods. We also hope to use this method to determine the effectiveness of balance training by measuring it over time.

The main limitation of this study is that the number of participants was small and it was not possible to compare differences between those with balanced and unbalanced occlusal contact state. Because occlusal correction using an intraoral appliance does not have a significant effect on physical fitness tests for athlete with stable occlusal contact state (Takahashi et al., 2023d), we intend to increase the number of participants in a future study in order to clarify the influence of occlusal contact state on balance ability, which would be expected to provide evidence that health management of the stomatognathic area or occlusal management contributes to safe and secure sports activities.

5. Conclusion

This study investigated the influence of occlusal conditions with the aim of clarifying the relationship between static balance and dynamic balance, using cross test trajectory diagram as an index. A relationship between static balance and dynamic balance was observed in the jaw position with no tooth contact (i.e., mandibular resting position) and under conditions where occlusal contact was evenly provided with a mouthguard. In other words, the R/E value reflects static balance, suggesting that the center of gravity can be moved efficiently in an internal environment with stable static balance. Furthermore, if the participant's occlusal contact state is unbalanced, occlusion may become a disturbance factor; therefore, it is recommended that the cross test be performed with the mandible in the resting position.

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Conflicts of Interest

The authors have no conflicts of interest relevant to this article.

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