

Impact of Improved Feedforward Control on Flight Time in Trampoline Competitions

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How to cite this paper: Takahashi, M., Bando, Y., & Fukui, T. (2025). Impact of Improved Feedforward Control on Flight Time in Trampoline Competitions. *Advances in Physical Education*, 15, 187-196. <https://doi.org/10.4236/ape.2025.152014>

Received: February 25, 2025

Accepted: May 10, 2025

Published: May 13, 2025

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Abstract

Purpose: The purpose of the present study was to clarify the effect of improved feedforward control resulting from better occlusal balance through a mouthguard intervention on flight time in trampoline competition. **Method:** Participants were 13 male trampoline gymnasts (17.8 ± 2.2 years). Feedforward control was evaluated with the cross test by using a center-of-gravity sway meter. The value obtained by dividing the rectangular area obtained from the product of the longitudinal movement distance and the lateral movement distance of the center of foot pressure by the outer peripheral area (i.e., R/E value) was used as an index of feedforward control. The trial was 10 consecutive straight jumps. The HDS all-in-one measurement system was used to measure the flight time. Measurements were performed under two conditions: not wearing a mouthguard and wearing a mouthguard. Comparisons of the R/E value or flight time between the wearing and not wearing mouthguard conditions were analyzed using a paired *t*-test. Correlation between the R/E value and flight time under each measurement condition was analyzed using Pearson's product moment correlation coefficient. **Results:** The R/E values and flight time were significantly higher with the mouthguard than without ($P < 0.05$). Under both conditions, the larger the R/E value, the longer the flight time, and a significant positive correlation was observed ($P < 0.05$). **Conclusion:** The results of this study show that feedforward control assessed by the cross test is improved by wearing a mouthguard, which helps to extend the flight time of straight jumps in competitive trampoline gymnastics.

Keywords

Feedforward Control, Flight Time, Trampoline Competition, Mouthguard, Occlusion

1. Introduction

Postural stability is achieved through the continuous activity of antigravity muscles and postural reflexes (Ghamkhar & Kahlaee, 2019). It can be broadly divided into static balance, which maintains a resting posture on stable, flat ground, and dynamic balance, which maintains equilibrium of the center of gravity to maintain the intended state in an environment with a changing base of support or center of gravity (Nagano, 2023). These evaluations are selected in response to a variety of individual factors, including health condition, age, musculoskeletal system, and any nervous system diseases. The sensory inputs from various parts of the body that contribute to postural stability are primarily via vision, somatosensation, and vestibular sensation, and information from these organs is integrated with the central nervous system to induce responses in the neuromuscular mechanisms (Fitzpatrick & McCloskey, 1994; Itaya, 2015).

Sporting activity is associated with the frequent occurrence of posture changes that are not encountered in everyday life. Feedforward control (predictive postural control) is active at this time, with disturbances predicted based on past experience, and the activity of posture-maintaining muscles precedes that of agonist muscles to stabilize posture after the disturbance. In addition, reactive postural control occurs frequently to maintain postural stability when an unexpected event occurs, improving the posture based on information from various sensory inputs so as not to deviate from the planned movement (Uchiyama, 1995; Otsuka & Hiyamizu, 2023).

The effects of interventions such as occlusal balancing and mouthguards on posture stability have been demonstrated in previous studies using measurements of static and dynamic body sway (Bando et al., 2019; Takahashi et al., 2024a, 2024c). We focus on occlusion, which can affect somatic sensation and vestibular sensation, two of the sensory inputs for postural adjustment (Gangloff et al., 2000; Takahashi et al., 2021), and has investigated the relationship of occlusion with postural adjustment and motor function in athletes. Previous studies have shown that the left-right balance of occlusal contact (occlusal balance) affects static center-of-gravity movement and agility and that improving occlusal contact by using a mouthguard helps to augment trunk stability during clenching (Bando et al., 2019; Takahashi & Bando, 2018; Takahashi et al., 2023a). Furthermore, in an evaluation of dynamic balance using the cross test in healthy men, it was revealed that clenching interventions affected dynamic balance only in individuals with good occlusal balance (Takahashi et al., 2024a). The higher the dynamic stability, the clearer the cross-test trajectory diagram, and the R/E value has been reported as an index that quantifies this relationship (Fukuyama & Maruyama, 2010). In other words, the R/E value is assumed to be an index that reflects the feedforward control function. However, there have been very few reports of research on feedforward control targeting trampoline gymnasts.

The purpose of the present study was to clarify the effect of improved feedfor-

ward control resulting from better occlusal balance through a mouthguard intervention on flight time in competitive trampoline gymnasts. The null hypothesis was that improving feedforward control would not affect flight time in trampoline gymnastics.

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 their participation.

2.2. Participants

The participants were 13 male trampoline gymnasts (mean age, 17.8 ± 2.2 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 11.8 ± 2.1 years and they trained 6 days a week for 3 h per day.

2.3. Mouthguard Fabrication

Mouthguards were 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 trimming and polishing, the mouthguards were fitted to the participants and adjusted so that all teeth made equal contact when the mouth was closed lightly (Bando et al., 2019; Takahashi et al., 2023a, 2023b). The occlusal contact state of the mouthguard was confirmed by occlusal examination using blue silicone (Bite Eye; GC Co., Tokyo, Japan) (Takahashi et al., 2023b).

2.4. Measurement of Feedforward Control

Feedforward control was evaluated with the cross test by using a center-of-gravity sway meter (GRAVICORDER GS-7; Anima Co., Ltd., Tokyo, Japan) (Fukuyama & Maruyama, 2010; Takahashi et al., 2024b, 2024c). Participants stood upright on the measuring table with their feet 5 cm away from the center line. Both upper limbs were in contact with the sides of the body. The participants were instructed to stand upright as a standard position and to move their upper bodies in the following order, taking 3 s for each: forward, standard position, backward, standard position, left, standard position, right, and back to standard position. The participants were instructed not to lift their heels during the measurement (Figure 1). Measurements were obtained under two conditions: not wearing a mouthguard and wearing a mouthguard. During the measurement, no instructions were given

on occlusion or clenching. The time for a single measurement was 30 s. The value obtained by dividing the rectangular area obtained from the product of the longitudinal movement distance and the lateral movement distance of the center of foot pressure by the outer peripheral area (i.e., R/E value) was used as an index of Feedforward control (**Figure 2**) (Takahashi et al., 2024b, 2024c).



Figure 1. Measurement of feedforward control using the cross test.

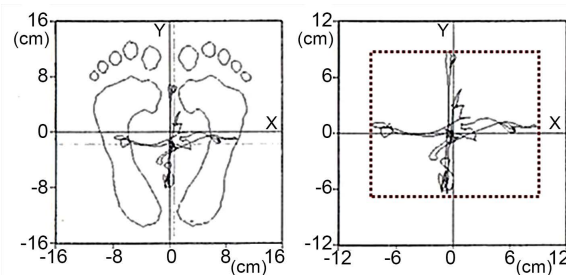


Figure 2. Example of a center-of-gravity locus diagram. The area surrounded by the dotted line is rectangular area.

2.5. Measuring Flight Time in Straight Jumps

The flight time of straight jumps was measured using an HDTs all-in-one measurement system (EU-7100; Eurotramp Trampoline Kurt Hack GmbH, Weilheim, Germany). Recording was started after calibration. The trial comprised 10 consecutive straight jumps, and the recording started after one preliminary jump from a stationary state. The flight time for each jump was recorded as the time the body was off the trampoline bed (**Figure 3**) (Takahashi et al., 2023c, 2023d).

2.6. Statistical Analysis

Statistical analysis was performed with SPSS ver. 17.0 software (SPSS Japan Inc., Tokyo, Japan), and the significance level was set at $P < 0.05$. As a result of normality testing using the Shapiro-Wilk test, normality was confirmed for each level of the R/E value and flight time.

Comparisons of the R/E value or flight time between the wearing and not wearing mouthguard conditions were analyzed using a paired t -test. The correlation between the R/E value and flight time under each measurement condition was analyzed using Pearson's product moment correlation coefficient.



Figure 3. Measurement of flight time, using an all-in-one measurement system (HDTs EU-7100). The red squares indicate the flight time of each jump, and the total flight time of the 10 jumps is shown at the bottom.

3. Results

The difference in the R/E value between the wearing and not wearing mouthguard conditions is shown in **Figure 4**. R/E values were significantly higher with the mouthguard than without ($P < 0.05$). It was confirmed that feedforward control was improved by wearing a mouthguard.

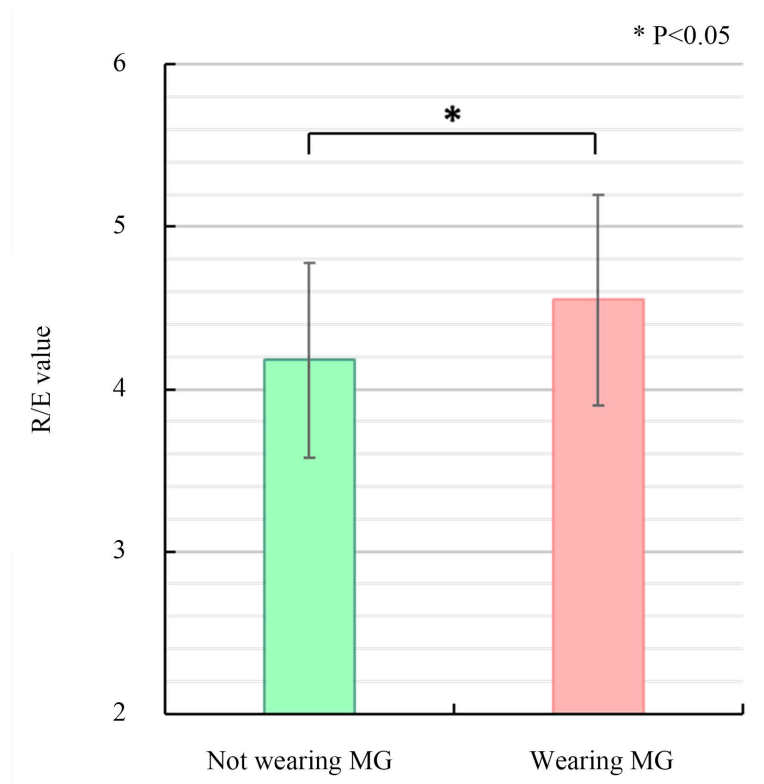


Figure 4. Difference in R/E value with or without a mouthguard. Error bar indicates standard error of the mean. * $P < 0.05$: denotes statistically significant difference. MG, mouthguard.

Figure 5 shows the difference in flight time depending on whether or not the mouthguard was worn. The flight time was significantly longer when the mouthguard was worn than not worn ($P < 0.05$).

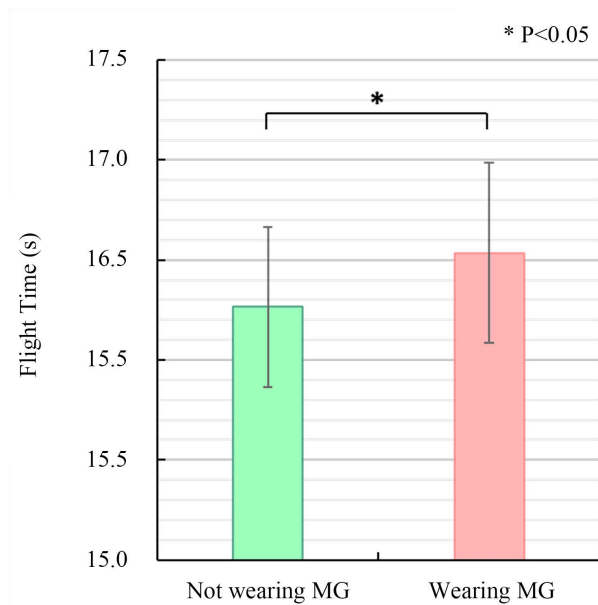


Figure 5. Difference in flight time with or without a mouthguard. Error bar indicates standard error of the mean. * $P < 0.05$: denotes statistically significant difference. MG, mouthguard.

Figure 6 shows the results of a correlation analysis between the R/E value and flight time according to whether the mouthguard was worn. Under both conditions, the larger the R/E value, the longer the flight time, and a significant positive correlation was observed ($P < 0.05$). In other words, the flight time was an index that reflected the R/E value (i.e., feedforward control).

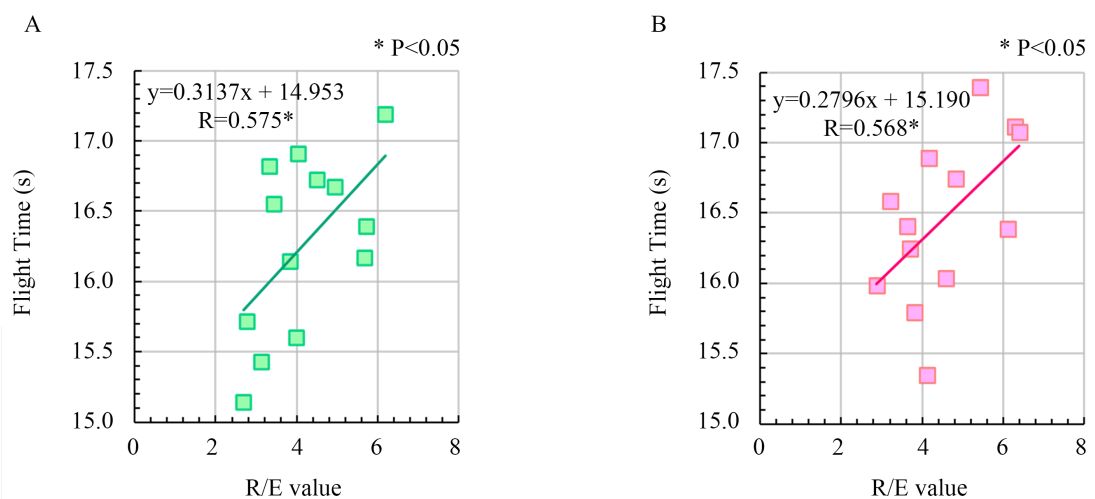


Figure 6. Results of correlation analysis between the R/E value and flight time according to mouthguard conditions. (A): Not wearing mouthguard. (B): Wearing mouthguard. * $P < 0.05$ denotes a statistically significant difference.

4. Discussion

The results of this study showed that the improvement in feedforward control associated with a mouthguard intervention increased the flight time in competitive trampoline gymnasts. Therefore, the null hypothesis—that improved feedforward control would not affect flight time in trampoline gymnastics—was rejected.

In terms of measurement conditions, this study set two conditions to determine the effectiveness of a mouthguard intervention. During the measurement, no instructions regarding occlusion, including clenching, were given and it was thus left to the participants' discretion. This is because a preliminary cross-test experiment revealed that some participants momentarily clenched their teeth when moving their upper body and that the timing of the teeth clenching depended on the participant. In addition, in a preliminary experiment in which a surface electromyogram was attached to the masseter muscle and a straight jump was performed, most of the athletes activated the masseter muscle immediately before landing. It is difficult to determine whether this muscle activity is an isotonic or isometric contraction, so it is not possible to determine whether clenching is occurring during the trial. Therefore, no instructions were given regarding clenching for each measurement item.

The results of this study showed that the R/E value was significantly higher when a mouthguard was worn than when it was not worn. The R/E value is an index that can be evaluated by assuming that there is no difference in rectangular area. In this study, the differences in the rectangular area between measurement conditions were analyzed in advance using a paired *t*-test, and no significant differences were found. Because the rectangular area in the cross test is an index that reflects the ankle strategy and hip strategy, it can be inferred that this value may be influenced by the range of motion of the hip and ankle joints (Shushtari et al., 2022). In general, clenching stabilizes the trunk or fixes joints (Takahashi et al., 2024a), so clenching would be expected to reduce the rectangular area. In contrast, when changing the direction of the body, clenching may occur instantaneously (Takahashi et al., 2020). In conjunction with this, occlusal correction using a mouthguard has also been revealed to have a positive impact on the performance of physical fitness tests that include cutting movements (Takahashi et al., 2023b). In this study, no instructions were given regarding clenching or occlusion but, because the mouthguard intervention affected the R/E value, it is possible that, at some point during the upper body movement during the cross test, dental contact, including clenching, or occlusion was used to stabilize the trunk. Because there was no significant difference in rectangular area between measurement conditions, it appears that the difference in the R/E value was caused by the difference in the peripheral area. In other words, it can be inferred that participants were able to move their upper bodies more smoothly when wearing a mouthguard compared to when they were not wearing one.

Motor function was evaluated by using the flight time of a straight jump. The straight jump is one of the basic movements in trampoline competitions. It has

been shown to be affected by occlusal contact conditions (Takahashi et al., 2023d). In addition, the state of the occlusal contact affects static balance (Bando et al., 2019), and there is a correlation between static balance and dynamic balance evaluated using a center-of-gravity sway meter (Takahashi et al., 2024c). Accordingly, and similar to the R/E value, it was predicted that an occlusal intervention using a mouthguard would affect the flight time. The present analysis revealed that flight time was increased by wearing a mouthguard. Electromyographic recordings confirmed that masseter muscle contraction occurred from just before landing until after takeoff, suggesting that stabilization of the center of gravity using occlusion may have led to longer flight times.

A positive correlation was observed between the R/E value and flight time, regardless of mouthguard use. This indicates that feedforward control measured by the cross test is related to motor function in trampoline competitions. Trampoline competition is a gymnastics event that emphasizes balance ability, and balance ability is a physical function that is emphasized in basic training. The average competitive experience of the participants in this study was 11.8 years, and it can be concluded that the effects of the balance training that they had performed from a young age were reflected in their competitive skills. It can also be seen as evidence that strengthening of balance training would improve competitive skills. Postural balance is an essential physical function for athletes that can affect not only competitive skills but also the incidence and severity of sports-related injuries. In addition to the importance of balance training, it is necessary to make everyone involved in the sport aware that occlusal balance correction has a positive impact on balance ability.

The main limitations of this study are that participants were limited to male gymnasts and the sample size was small. Evaluation using a center of gravity sway meter may be affected by the menstrual cycle (Emami et al., 2019; Lee et al., 2017), so when targeting female athletes, consideration must be given to the timing of measurements. Furthermore, because individual differences due to athletic history and athletic level may affect the extent of the effects of mouthguard intervention, we would like to conduct further investigations over a longer period of time, increase the sample size, and re-examine the results. In addition, with respect to jumping in trampoline competitions, by analyzing the muscle activity of the trunk and lower limb muscle groups related to the movements from landing to takeoff, it may be possible to determine the effects of occlusal interventions in more detail, and we need to consider this in the future. By clarifying these points, it becomes possible to clarify the evidence that management of the health of the stomatognathic region or occlusal management can lead to safe sporting activity and improved athletic ability.

5. Conclusion

The results of this study show that feedforward control assessed by the cross test is improved by wearing a mouthguard, which helps to extend the flight time of

straight jumps in competitive trampoline gymnastics. This suggests the importance of balance training and indicates that the improvement in feedforward control achieved using an occlusal intervention can contribute to motor function in trampoline competitions.

Funding

This work was supported by JSPS KAKENHI Grant Number JP23K10617.

Conflicts of Interest

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

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