Effects of wearing a custom-made mouthguard during static exercise and dynamic exercise on masticatory muscle activity and postural sway in athletes with cerebral palsy

（脳性麻痺アスリートのカスタムメイドマウスガード装着が
運動時の咀嚼筋活動と身体の動揺に及ぼす影響）

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Ⅰ ABSTRACT

Aim

Oral health is closely related to the general condition of athletes. Oral diseases can decrease their performance by affecting their concentration during games and practice sessions. Appropriate education is therefore required regarding the importance of dental support. Dental support for sports is necessary not only for healthy people but also for people with CP. We introduced periodic dental examinations and fabricated custom-made mouthguards (CMGs) for athletes with cerebral palsy (CP). This study aimed to determine the effects of wearing a CMG on masticatory muscle activities in athletes with CP while static exercise and dynamic exercise.

MATERIALS AND METHODS

Research 1

Thirteen athletes with CP (male, n = 12; mean age, 27.3 ± 8.96 y) and 10 healthy male controls (mean age, 28.5 ± 1.35 y) participated in the present study. The CMG comprised 2-mm-thick polyolefin sheeting. All participants underwent dental checks and occlusal contact areas were measured with and without a CMG. We simultaneously measured gravitational sway at the center of gravity (COG) with the eyes open and close, as well as masseter and digastric muscles (opening and closing muscles) activities with or without a CMG. Myoelectric measurement and COG sway measurement were done at the same time. Data were statistically analyzed using two-way mixed analyses of variance.

Research 2

Nine athletes with CP (male, n = 9; mean age, 26.7 ± 8.40 y) and 9 healthy male controls (mean age, 28.5 ± 1.35 y) participated in the present study. The CMG comprised 2-mm-thick polyolefin sheet in the same way as for Research 1. The myoelectric measurement was evaluated using the muscle activity of masseter and digastric muscles in the same way as

for Research 1. Gait measurement was evaluated using the gait trajectory of upper body trunk and lower body trunk. Myoelectric measurement and gait measurement were done at the same time. Data were statistically analyzed using two-way mixed analyses of variance.

RESULTS

Research 1

Indices for decayed, missing and filled teeth did not significantly differ between athletes and controls. However, the occlusal contact area significantly increased in athletes when wearing a CMG. Although COG sways slightly differed between having eyes open and closed in athletes with CP, masticatory muscle activity increased and COG sway decreased. On the other hand, no significant change was observed in the controls.

Research 2

Athletes with CP wearing CMG during gait showed a significant increase in masseter muscle activity and an increasing trend in digastric muscles activity and showed the effect of improving gait to the lower body trunk in the left-right direction. On the other hand, no significant change was observed in the controls.

CONCLUSION

The findings suggest that wearing a CMG might change the modality of masticatory muscle activity in athletes with CP and might help to improve balance during static exercise and dynamic exercise. Therefore, improvement of balance during exercise can help reduce the risk of falls and injuries in these patients, in addition to consciously improving athletic ability of individuals with CP.

Ⅱ INTRODUCTION

Sports dentistry is the branch of sports medicine dealing with preventing and treating dental trauma and oral diseases associated with exercise [1]. In other words, the main role of the sports dentist is to provide mouthguards and face masks which prevent orofacial trauma and concussion of the brain and to control and educate oral hygiene so as not to reduce exercise ability to athletes [2]. We have been working on towards the Tokyo Olympic and Paralympic Games in 2020 as sports dentists. Generally, the Olympics draw more attention than the Paralympics because of its population. However, we see much potential for growth not only in the Olympics but also the Paralympics by doing dental support and research of people with disabilities. Because sport brings many benefits to people with disabilities.

First of all, sport positively affects the mind and body by promoting mental stability and physical health. In addition to these health aspects, sport fosters a relationship with society that promotes vitality and improves the quality of life among people with disabilities. This, in turn, imparts self-confidence to people with disabilities [3,4]. Many events are now available for people with and without disabilities to enjoy and practice sports without barriers in the same way regardless of disability. Opportunities for disabled people to practice and a cooperative infrastructure of athletes and supporters should be established to promote sports for the disabled. Dentists should become involved in sport by delivering proactive support.

Therefore, the authors have provided dental support at the Special Olympics and to athletes with cerebral palsy (CP) who play CP football as part of a strategy to support disabled sports. Support was provided to floor hockey athletes in the Special Olympics in the form of dental checks in the Special Smile program and the provision of custom-made mouthguards (CMG). In addition, the use of CMGs as opposed to pre-formed mouthguards has been advocated [5]. As team dentists for CP football athletes (athletes with CP), we have provided dental examinations, oral hygiene guidance, dental treatment, and CMGs; thus, our activities have ranged from oral care guidance to the prevention of oral injury [6–8]. Dental support in the form of examinations and the provision of CMGs is still available to CP football teams.

Reports to date have described that CMGs exert many beneficial effects, including a reduction in the frequency or prevention of maxillofacial trauma such as tooth injury, soft tissue laceration, temporomandibular joint injury, concussion or mandibular fracture, as well as maintaining the position of the temporomandibular joint [9–13]. Several recent studies have investigated improving competitive ability as a new role for the CMG [14–19].

However, almost all of these studies assessed healthy people [20–22], and few studies have focused on people with disabilities. A previous report has explored the underlying mechanism by investigating the relationship between masticatory muscle activity due to wearing a CMG and center of gravity (COG) sway. The results suggested that athletes with CP who wear a CMG have a different modality of masticatory muscle activity from that of healthy people, and that COG sway was improved. Actually, these studies had very few participants, and body sway was measured only with the eyes open. Therefore, dental studies which are targeting sports for people with disabilities are rarely conducted. People with disabilities may have different jaw functions during exercise compared to healthy people, but dental support is done in the same way. In particular, if wearing CMG can support not only trauma prevention but also exercise capacity, the significance of doing dental support for handicapped athletes. It should be considered the influence of wearing CMG on the more detailed exercise ability and masticatory muscle activity during exercise.

Generally, Exercise can be divided into static exercise and dynamic exercise. The static exercise involves little or no changes in muscle length or joint movement but dynamic exercise involves changes in muscle length and joint movement [23]. In other words, even in the same exercise, the way of using muscles and joints are different between static and dynamic exercise. That is, the influence of wearing CMG on athletes with CP may be different between static and dynamic exercise and it is necessary to consider both. Static standing postural is a typical static exercise that is performed every day and many studies using the COG sway have been performed [23]. In addition, the stats of the eyes open and close may cause changes in jaw function and posture maintenance during static standing postural and it is necessary to examine both. On the other hand, gait is a representative dynamic exercise routinely performed and is also used for evaluating and predicting overall health [24]. Therefore, COG sway and gait are considered to be an important indicator to evaluate basic static and dynamic exercise.

In the present study, we investigated the effects of wearing a CMG on masticatory muscle activity during basic static exercise (COG sway) and dynamic exercise (gait) in athletes with CP while measuring COG sway and gait.

Ⅲ MATERIALS AND METHODS

Research 1: Effects of wearing a custom-made mouthguard during static exercise on masticatory muscle activity in athletes with cerebral palsy

Participants

The present study which include 13 athletes with CP from a CP soccer club team, who had received dental support from our personnel (12 men, 1 woman; mean age, 27.3 ± 8.96 y; 11 athletes with athetoid type CP, 1 acquired motility disturbance; athletes) and innate or acquired physical movement disability due to CP, as well as cerebrovascular disease and head injury, and 10 healthy men (mean age, 28.5 ± 1.35 y; controls) without subjective or objective disorders of the stomatognathic system, cervicofacial area, etc. The study was implemented in accordance with the Declaration of Helsinki (2013 revision), and all those enrolled received an explanation of the purpose of the study before providing written, informed consent to participate (Ethics Review Committee, Nihon University School of Dentistry at Matsudo; Approval No: EC16-013).

CP football

The team sport of CP football (also known as seven-a-side football) became an official Paralympic event in 1984. It is played by athletes with movement disorders because of CP, traumatic brain injury, or stroke, and those who have difficulty in maintaining posture or walking [25]. Athletes must be able to walk independently without the use of protective equipment. In principle, teams comprise athletes with class C5–C8 disabilities. The game is played according to the rules of the Fédération Internationale de Football Association, with the following changes: no offside, single-handed underarm throwing is allowed, and a smaller pitch and goal than those of regular 11-a-side football. The first and second halves of international matches are both 30 min, halftime is 15 min, and up to three substitutions are permitted [26].

Dental check up

Annual dental checks were held at the time of pre-season meetings. Considering the burden on athletes, these meetings provide good opportunities for almost all athletes to meet and interact. The checkups were all conducted visually by the same dentist using a dental mirror, and decayed, missing, and filled teeth (DMFT) indices were calculated according to the standards of the Fédération Dentaire Internationale (FDI) [27].

The DMFT indices of the athletes with CP were compared with 86 healthy people of the same generation in the nationwide FY2016 Survey of Dental Diseases, which the Ministry of Health, Labour and Welfare in Japan implement every five years.

Manufacture of custom-made mouthguards

CMGs were manufactured by pressure-forming polyolefin-based 2-mm MG21 sheets (CGK Corp., Hiroshima, Japan) according to a standard protocol. The CMG was shaped approximately 2 mm above the cervical line on the labial side to completely avoid the frenum, and it follows the cervical line on the palatal aspect. The basic CMG also extends in the posterior direction to the distal side of the maxillary first molar. The occlusal surface of the CMG can be adjusted as needed by softening it on a dental model with gentle heat delivered using a hot air burner (Erkodent, Pfalzgrafenweiler, Germany) and then fitting it inside the mouth and directing the recipient to carefully close the mouth, ensuring the absence of lateral deviation.

Occlusal contact records

Occlusal contact was recorded to determine changes in occlusal relationships in the athletes and controls when wearing and not wearing a CMG. Contact was recorded using conformity test Blue Silicone® (GC Co. Ltd., Tokyo, Japan), which is an addition-type silicone. Impressions were taken by loading Blue Silicone® onto the mandibular arch and then having the participants close their mouths in the maximal intercuspal position with minimal force. The participants were seated in a chair so that the occlusal plane remained parallel to the floor during recording, and they were required not to move the mandible or change posture for 90 s until the silicone had completely hardened. The surface area of occlusal contact was evaluated using a dedicated Biteye BE-1 analytical device (GC Co. Ltd., Tokyo, Japan). A silicone thickness of ≤ 50 μm was judged to indicate occlusal contact [28].

Myoelectric measurements

The volume of masticatory muscle activity was measured using a Polymate Mini AP108 (Miyuki Giken, Tokyo, Japan). Among the various masticatory muscles, we assessed the superficial layer of the left and right masseter muscles that close the mouth, and the belly of the left and right anterior digastric muscles that open the mouth. We used Ag-AgCl electrodes, and care was taken to ensure that the cords connecting the electrodes did not affect biomechanics. The electrodes were affixed such that the distance from the belly of the corresponding muscle was 10 mm.

The maximum voluntary contraction (MVC) of each muscle was measured before starting the experiment. The MVC of the masseter muscle was determined by maximum clenching in the intercuspal position, and that of the digastric muscle was determined by placing the thumb of each hand on the submental region, without touching the electrodes, and maximally opening the mouth against resistance [29, 30]. The MVC measurements were repeated three times, and the largest of the three values was taken as the MVC for that muscle. The relative ratio of activity for each muscle was determined as %MVC and %MVC root mean square was also determined as %MVC-RMS. The %MVC-RMS value shows the mean RMS value for muscle activity expressed as %MVC during COG sway measurement in 60 seconds. The %MVC-RMS values of the left and right masseter and digastric muscles were calculated, then the means of the left and right values were calculated and used as the respective %MVC-RMS values to determine muscle activity volume.

These measurements were taken under circumstances of wearing and not wearing a CMG, and with the eyes open and closed. Each measurement was repeated three times for 60 s, and the mean value was then calculated. The order of measurements when wearing and not wearing a CMG was random. The position of the jaw at the start of measurements was that with the mandible at rest and no instructions given regarding the position of the mandible after starting measurements.

Measurement of center of gravity sway

We used ECG-1500AK (Kyowa Co., Ltd., Fukuoka, Japan) to measure COG sway. Based on the standards of the Japan Society for Equilibrium Research, measurements proceeded with participants standing upright with their arms by their sides in a quiet room with uniform illumination to avoid postural deviation owing to aural or visual stimuli. Tests proceeded with eyes open and closed for 60 s each. Measurements were taken with the eyes open by having the participants steadily gaze at a point set at eye level two meters in front of them. Measurements were taken with the eyes closed and the head upright while mentally visualizing the same visual point. COG sway was evaluated based on the outer area (mm^2) and total trajectory length (mm). Because COG sway and myoelectric values were simultaneously measured, the start times of both measurements were matched using a synchronization system.

Statistical analysis

The DMFT indices of CP athletes calculated from the results of dental checkups were compared with those for a Japanese population within the same generation in the FY2016 Survey of Dental Diseases using independent *t*-tests. Changes in occlusal contact were compared between athletes and controls while wearing a CMG or not using paired *t*-tests. The effects of wearing a CMG on masseter and digastric muscle activities and COG sway (total area and length) in the athletes and controls were analyzed using a two-way mixed analysis of variance (ANOVA).

Data were statistically analyzed using SPSS 24.0J for Windows Japan (IBM Co., Ltd. Tokyo, Japan) and the level of significance was set at 5% .

Research 2: Effects of wearing a custom-made mouthguard during gait on masticatory muscle activity in athletes with cerebral Palsy

Participants

The present study included 9 athletes with CP (8 men, 1 woman; mean age 26.7 ± 8.40 years; 8 athletes with athetoid type CP, 1 acquired motility disturbance; athletes) from a CP soccer club team, who had received dental support from our personnel and had innate or acquired physical movement disability due to CP, cerebrovascular disease, and head injury. Nine healthy men (mean age, 28.4 ± 1.42 years; controls) without subjective or objective disorders of the stomatognathic system, cervicofacial area, and so on were also recruited. The study protocol was implemented in accordance with the Declaration of Helsinki (2013 revision), and all those enrolled received an explanation of the purpose of the study before providing written informed consent to participate (Ethics Review Committee, Nihon University School of Dentistry at Matsudo; Approval No: EC16-013).

Manufacture of custom-made mouthguards

CMG manufacturing was carried out in the same way as Research 1.

Myoelectric measurement

Myoelectric measurement was carried out in the same way as Research 1.

Gait measurement

The measurement of gait was carried out using THE WALKING (MicroStone Corp., Nigata, Japan). THE WALKING can measure and evaluate the trajectory of the trunk without disturbing walking by wearing an accelerometer (MVP-RF8-GC-500, MicroStone Corp., Nagano, Japan) in two positions of the upper body trunk (center of sixth thoracic vertebral position) and lower body trunk (center of third lumbar position) with the exclusive belt.

The measurement was carried out by walking 10 m at preferred speed on a flat surface with a straight line drawn and an electromyogram meter attached; measurement was obtained three times each for wearing and not wearing CMG [31,32]. The order of measurements when wearing and not wearing a CMG was random. In addition, measurements were carried out on familiar sports shoes [33]; the position of the jaw at the start of the measurements was that with the mandible at rest and no instructions were given regarding the position of the mandible after starting measurements. The sampling frequency of the acceleration data was 100 Hz (input) and transmitted to the personal computer through Bluetooth communication. A 4-step walking cycle, which is a steady-state walking of 4 to 7 steps from the start of gait, was used in the analysis [34], and gait was evaluated using the lateral and longitudinal sway ratios, gait smoothness, gait levelness, as well as symmetry of the upper and lower body [35].

Gait and myoelectric measurements were both taken simultaneously using a synchronization system, which was utilized to match the starting times of both measurements.

Statistical analysis

The effects of wearing the CMG on masseter and digastric muscle activities and gait in the athlete with CP and healthy groups were analyzed using a two-way mixed analysis of variance (ANOVA). Statistical analysis was carried out using SPSS (SPSS 24.0J for Windows Japan; IBM Co., Ltd. Tokyo, Japan) statistical software, with the level of significance set at 5%.

Ⅳ RESULTS

Research 1: Effects of wearing a custom-made mouthguard during static exercise on masticatory muscle activity in athletes with cerebral palsy

Dental check up

The DMFT indices of the athletes with CP (Mean±SD : 5.67±4.29) and of Japanese individuals of the same generation from the (2016) Survey of Dental Diseases (Mean±SD : 8.50±4.90) showed similar values.

Occlusal contact area

Table 1 shows that the occlusal contact area at the maximal intercuspal position significantly increased when athletes with CP wore a CMG, but did not significantly differ regardless of wearing a CMG in controls (p = 0.022 vs. p = 0.212)

Masticatory muscle activity during COG sway

The volume of masticatory muscle activity while measuring COG sway was compared using a two-way mixed ANOVA with the group (CP athletes and controls) and condition (with and without a CMG) as the primary factors.

Table 2 shows that masseter and digastric muscle activities significantly interacted when the eyes were open ($F[1, 21] = 5.32$, p = 0.03 vs. $F[1, 21] = 5.23$, p = 0.03). Simple main effect analysis showed significantly higher mean values for the masseter and digastric muscles in the athletes when wearing the CMG ($F[1, 21] = 13.70$, p = 0.001 and $F[1, 21] = 12.42$, p = 0.002, respectively), but not in the controls ($F[1, 21] = 0.03$, p = 0.860 and $F[1, 21] = 0.00$, p = 0.962, respectively). Interaction was significant only with the masseter muscles with the eyes closed (F[1, 21] = 6.3, *p* = 0.020). Simple main effect analysis showed significantly higher mean values for the athletes, but not the controls when wearing the CMG (F[1, 21] = 14.32, *p* = 0.001 and (F[1, 21] = 0.00, *p* = 0.99, respectively). Interaction was not significant for the digastric muscles, but the mean value was greater when wearing the CMG only in the athletes (eyes open: F[1, 21] = 12.42, *p* = 0.002); eyes closed: F[1, 21] = 5.10, *p* = 0.035). Mean values in the controls did not significantly differ between having their eyes open and closed (F[1, 21] = 0.00, *p* = 0.962 vs. F[1, 21] = 0.01, *p* = 0.912).

Center of gravity sway

We assessed COG sway using a two-way mixed ANOVA with the primary factors of athletes and controls wearing a CMG or not.

Table 3 shows that significant interaction was identified in the total length of sway with the eyes open and closed (F[1, 21] = 4.85, *p* = 0.039 vs. F[1, 21] = 6.14, *p* = 0.02). Simple main effect analysis showed significantly lower mean total length when the athletes wore the CMG (eyes open vs. closed: F[1, 21] = 10.91, *p* = 0.003 vs. F[1, 21] = 13.40, *p* = 0.001), but not the controls (eyes open vs. closed: F[1, 21] = 0.00, *p* = 0.974 vs. F[1, 21] = 0.01, *p* = 0.933).

No significant interaction was found for total area with the eyes open or closed, but the mean was lower when wearing the CMG in the athletes (eyes open vs. closed: F[1, 21] = 4.60, *p* = 0.044 vs. F[1, 21] = 7.75, *p* = 0.011). Mean values did not significantly differ in the controls (eyes open vs. closed: F[1, 21] = 0.00, *p* = 0.966 vs. F[1, 21] = 0.00, *p* = 0.992).

Research 2: Effects of wearing a custom-made mouthguard during gait on masticatory muscle activity in athletes with cerebral Palsy

Masticatory muscle activity during gait

The volume of masticatory muscle activity while measuring gait was compared using a two-way mixed ANOVA with the group (athletes with CP and controls) and condition (with and without a CMG) as the primary factors.

Table 4 shows that interaction was significant only in the masseter muscles [F(1,16)=6.95, p=0.018]. Therefore, the simple main effect analysis showed significantly higher mean values for the masseter muscles in the athletes with CP when wearing the CMG [F(1,16)=15.56, p=0.001]. The interaction was not significant for the digastric muscles [F(1,16)=3.86, p=0.067], but the mean value was greater when wearing the CMG in the athletes with CP [F(1,16)=9.62, p=0.007]. In contrast, the mean value was not significantly different in the controls.

Gait sway

The gait sway was compared using a two-way mixed ANOVA with the group (athletes with CP and controls) and condition (with and without a CMG) as the primary factors.

Table 5 shows that interaction was not significant for the lateral sway ratio and the symmetry of the lower body [the lateral sway ratio: F(1,16)=2.12, p=0.165), the symmetry of the lower body: F(1,16)=0.029, p=0.600)], but the mean value was greater when wearing the CMG only in the athletes with CP [the lateral sway ratio: F(1,16)=5.58, p=0.031), the symmetry of the lower body: F(1,16)=0.515, p=0.037]. There was no significant difference in the longitudinal sway ratio, gait smoothness, gait levelness, and symmetry of the upper body of the athletes with CP. On the other hand, the mean value was not significantly different in the controls.

Ⅴ DISCUSSION

Research 1 investigated the effects of wearing a CMG on COG sway and masticatory muscle activities when the eyes were open and closed, considering COG sway as static exercise and the measurement of masticatory muscle used the masseter and digastric muscles as opening and closing muscles

Research 2 investigated the effects of wearing a CMG on gait sway and masticatory muscle activities during their gait, considering gait as dynamic exercise and the functions of the masseter and digastric muscles being to close and open the mouth respectively.

The results showed that static exercise (COG sway) and dynamic exercise (gait) have improved when the athletes with CP wore a CMG during the exercise, and that their masticatory muscle activities of CP athletes were different from those of the controls, suggesting that jaw movements are different in the athletes.

1. Subject

1-1 Athletes with CP

Subjects of athletes with CP has movement disorders because of CP, traumatic brain injury, or stroke, and those who have difficulty in maintaining posture or walking. Athletes must be able to walk independently without the use of protective equipment.

1-2 Dental check up

We initially found during dental checks that oral status did not significantly differ between the athletes with CP and a Japanese population of the same generation. However, Suzuki et al. [7] found that the DMFT indices of the oral status of a CP football team in 2011 were 12.4 teeth, whereas that of the same team in the present study was 5.67 teeth. The oral milieu of athletes with CP has steadily improved over time and is now equivalent to that of healthy people. While this might be largely a result of improved dental care for people with disabilities in Japan, but as team dentists, we consider that this might also be partly associated with consistent dental checkups and oral hygiene guidance.

1-3 Occlusal contact records

The occlusal contact area significantly increased in athletes with CP when wearing a CMG compared with the controls. The main factor for this might be that the CMG makes it easier to maintain the mandible in position between the teeth than when adopting the maximum intercuspal position, so the athletes could manage more stable occlusion. When the occlusal contact area is determined using silicone materials, the contact surface area increases with increasing occlusal strength [36]. Suzuki et al. [6–8] reported that athletes with CP tend to try to stabilize their jaw position by routinely clenching their teeth, and that even if these athletes are instructed to hold the mandible in place only with the amount of force needed to maintain upper and lower occlusal contact, the unconscious habit of routinely clenching the teeth might have caused the increase in contact area.

Moreover, as athletes with CP have hypertonia and unpredictable involuntary muscle activities, they might have coped with this by unconsciously clenching their teeth to maintain the mandible in a fixed position during the 90-s test period when the CMG was in place. The phenomenon of a completely different result from healthy people is therefore of interest.

On the other hand, the occlusal contact area increased in athletes with CP while wearing a CMG, suggesting that wearing a CMG affects masticatory muscle activity.

2. Masticatory muscle activity

2-1 Masticatory muscle activity during static exercise (Center of gravity sway)

Masticatory muscle activity during various sport-related movements has been documented, and many authors have given instructions on clenching teeth [37,38]. However, humans do not always clench their teeth during static or dynamic exercise. Therefore, the effects of wearing a CMG on masticatory muscle activity in a natural state without specific instructions to clench the teeth required investigation. Here, we deliberately measured COG sway under a natural state in which instructions regarding jaw position or occlusal status were not given.

Masseter and digastric muscle activities significantly increased among athletes with CP while wearing a CMG with their eyes open, but not in the controls. Masseter muscle activity also significantly increased in athletes with CP while wearing a CMG with their eyes closed. Digastric muscle activity tended to increase in the athletes, but the difference did not reach significance. Muscle activity did not significantly change in the controls with the eyes open or closed.

The above results suggest that when athletes with CP wear a CMG, they can maintain their jaw position because of an increase in the occlusal contact area. The results also suggest that athletes try to use the masticatory muscle groups to maintain jaw position via more powerful exertion of the muscles used to open and close the mouth. This phenomenon is not found in healthy people, and it might help to explain the increase in occlusal surface area. If wearing a CMG affects masticatory muscle activity in athletes with CP, it could be a step toward improving their competitive ability.

2-2 Masticatory muscle activity during dynamic exercise (Gait)

Athletes with CP showed a significant increase in the masseter muscle activity when wearing CMG. Digastric muscle activity tended to increase in the athletes wearing CMG. Masseter and digastric muscles activities did not significantly change in the controls. These were similar to the result in the static exercise. For these reasons, it was shown that athletes with CP naturally fix their jaw position during gait by softly clenching the CMG. Moreover, digastric muscle activity had a tendency to increase; thus, wearing CMG may have influenced not only the closing muscles but also the opening muscles. In other words, as with static exercises, there is a possibility that CMG wearing allows the masticatory muscle (opening and closing muscles) to fix the mandible. This phenomenon is not found in healthy people, and wearing CMG might help to increase occlusal surface area as with static exercise. If wearing a CMG affects masticatory muscle activity in athletes with CP, it could be a step toward improving their competitive ability.

3. Static exercise (Center of gravity sway)

All humans have some attitude unsteadiness, and equilibrium in the body is controlled by moving the COG in response. Failure to compensate for unsteadiness in all directions by COG sway would result in an unstable posture or falls [39]. Measuring COG sway is one way to objectively evaluate such instability. Therefore, we measured COG sway as a static exercise with the eyes open and closed.

The total length of sway significantly decreased in athletes with CP when wearing a CMG with their eyes open and with their eyes closed, and while this difference was not significant, the total area tended to decrease. Neither of these parameters significantly differed in the controls. These results suggest that wearing a CMG promotes a decrease in COG sway during static exercise in athletes with CP. Therefore, wearing a CMG during static exercise probably affects the maintenance of a posture and withstanding unintentional postural instability, which are aspects of improved exercise performance.

Measuring COG sway in athletes with CP with their eyes open probably reflects essentially unconscious masticatory muscle activity and the COG sway that naturally occurs throughout life. The results suggest that when wearing a CMG with the eyes open, these athletes maintained the position of the mandible not by firmly clenching the teeth, but rather by coordinating the opposing movements of opening and closing the mouth, thereby stabilizing their COG sway. Several reports have described a fixed position of the mandibular jaw [38,40,41]. According to Hellman et al., a mandibular position stabilized using the mandibular condyle and temporomandibular fossa improves COG sway more than maximal intercuspal or eccentric occlusal positions. In this study, the masticatory muscle groups are used to maintain jaw position using CMG via more powerful exertion of the muscles used to open and close the mouth. The digastric muscle opens the mouth and pulls the jaw backward. The increase in digastric muscle activity caused by wearing a CMG indicates that the athletes try to maintain the position of the mandible by pulling the mandibular condyle backward and pushing against the posterior wall of the temporomandibular fossa. Masseter muscle activity would then increase together with this, suggesting that the athletes might have attempted to hold the mandible in place more firmly by coordinating the masseter muscles with the muscles that close the mouth.

The COG values obtained with the eyes closed probably reflect masticatory muscle activity and COG sway under conditions where the absence of visual information depletes the sense of balance and causes psychological anxiety. These results suggest that when wearing the CMG with their eyes closed, unlike having their eyes open, the athletes held the mandible in place by clenching their teeth via the muscles that close the mouth to a greater extent than those used to open the mouth to maintain COG sway. Jaw movements in which the teeth are clenched to retain posture seem unlikely in healthy people [40,41] and it is probably a trait of athletes with CP. One report has indicated that clenching the teeth might stabilize posture by maintaining the position of the leg [42,43]; thus, if the method of maintaining posture differs between athletes with CP and healthy people, the athletes might instinctively firm up the leg by clenching the teeth in an attempt to retain and stabilize posture. In situations where maintaining posture is difficult or when visual and/or other types of sensory information are unavailable, sensations from the temporomandibular joint receptors associated with occlusal status play an important role [44]. The present findings that wearing CMG results in the mandible being held in position with increased stability support the results of these previous studies.

4. Dynamic exercise (Gait)

The use of gait analysis system with an accelerometer is increasing. The accelerometer is a cost-effective tool that allows taking measurements without taking too much space and time [24,45]. An accelerometer is attached to the limbs and trunk according to the purpose; in particular, the trunk provides reliable indications of full-body movement is generally used [31,46]. Also, Trunk accelerometric gait analysis was reported to be a reliable measurement method [31]. Therefore, we measured gait as a dynamic exercise using the accelerometer.

In this study, we evaluated the lateral and longitudinal sway ratios, gait smoothness, and gait levelness, as well as the symmetry of the lower and upper body. The quality of gait in the left-right direction was evaluated using the lateral sway ratio as well as the symmetry of the lower and upper body. The lateral sway ratio and symmetry of the lower body improved in the athlete with CP when wearing the CMG. This was not demonstrated by the controls.

The lateral sway ratio is the ratio of the left-right width of the lower trunk to the left-right width of the upper trunk, with lower values indicating unstable upper body and increased risk of falling. The lateral sway ratio increases when athletes with CP wear CMG, indicating that the gait sway decreases. When supporting the weight with one foot during the gait, the body is firmly supported because of the decreased swaying movements owing to the decreased inclination of the body. It was also indicated in static exercise, clenching fixes the leg joint by constricting the muscle around the leg joint (43,44). In a study on static exercises, it was suggested that the unconscious biting of the CMG results in the decreased sway of COG. Namely, it was considered that clenching occurred because the masseter muscle activity increased, which consequently resulted in fixation of the leg joint, thereby enabling the individual to support more weight with one foot; thus, it is considered that the left-right sway has decreased. In addition, controls do not have walking difficulty and are able to support their weight with one foot; thus, it is considered that difference in gait due to wearing and not wearing the CMG is unlikely to occur.

The symmetry of the lower body is the inner product similarity between the right and left sides of the lower body trunk trajectory, and if there is a difference in the movement of the lower body trunk, the value decreases. Athletes with CP showed a tendency of the lower body trunk movement to be homogenized to the left and right when wearing CMG. As in the lateral sway ratio, the fixation of the leg joint by wearing the CMG allows the individual to step more on the affected side; as a result, the quality of walking improved and it is considered that the movement of the lower body trunk approaches bilaterally and is symmetrical. Similar to the lateral sway ratio, controls do not have difficulty in walking; thus, it is thought that the difference in gait due to wearing and not wearing the CMG is unlikely to occur.

Moreover, the symmetry of the upper body did not improve significantly when wearing CMG in both the athletes with CP and controls. As the factors that improvement was not recognized in the symmetry of the upper body against improvement of the symmetry of the lower body, improvement of movement of the upper body including arm swing is needed than influence by foot stepping, as a result, there was no significant change by wearing CMG.

The quality of gait in the front-back direction was evaluated using the longitudinal sway ratio. The longitudinal sway ratio did not significantly improve despite the use of CMG in both athletes with CP and controls. The front-back swaying is swaying to the gait direction, and unlike left-right swaying, the leg joint moves greatly in the front-back direction. Therefore, fixation of the leg joint when wearing CMG is difficult to achieve, or it may not be effective even if it fixation is achieved. The quality of gait in the up-down direction was evaluated using gait levelness, whereas the quality of gait in the three-dimension direction was evaluated using gait smoothness. Gait levelness and smoothness did not significantly change when wearing CMG in both athletes with CP and controls. This may be attributed to the fact that gait levelness and smoothness depend on the original gait ability, including the characteristic of foot landing, of the individual, and we considered that improvement in these areas could not be obtained even when wearing CMG. From these results, it was demonstrated that CP athletes showed gait improvements in the lower body trunk in the left-right direction when wearing CMG while walking.

Wearing a CMG during static and dynamic exercise resulted in athletes with CP being able to increase their volume of masticatory muscle activity and improve their COG sway and gait sway. Thus, the CMG might become essential not only for preventing physical trauma but also for supporting improvements in balance.

Ⅵ CONCLUSION

Occlusal contact increased in the athletes with CP as a result of wearing a CMG, and an increase in masticatory muscle activity and a decrease in COG sway and gait sway. It is suggested that wearing a CMG may allow athletes with CP to easily maintain the position of the mandibular jaw and it may help to maintain their posture. These findings suggest that improvement of maintaining posture can help reduce the risk of falls and injuries for the participants.

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Ⅷ TABLES AND FIGURES

Table.1 Occlusal contact area of athletes with CP wearing and not wearing a CMG

Group	N	With CMG		Without CMG		*p*
		M	SD	M	SD	
CP	13	39.40	21.56	17.28	11.17	0.02
Control	10	22.28	22.81	12.23	11.20	0.21

CP: athletes with CP

Table.2 Masticatory muscle activity during COG sway measurement of athletes with CP wearing and not wearing a CMG

				Without CMG		With CMG		CMG× Group		CMG		Group		Simple main effect	
Eyes	Muscle	Group	N	Mean	SD	Mean	SD	F	*p*	F	*p*	F	*p*	F	*p*
Open	Masseter muscle	CP	13	1.71	0.80	3.10	1.88	5.32	.031	6.63	.018	28.73	<.001	13.70	.001
		Control	10	0.40	0.21	0.47	0.31							0.03	.860
	Digastric muscle	CP	13	3.67	2.73	4.70	2.86	5.23	.033	5.57	.028	11.29	.003	12.42	.002
		Control	10	1.16	1.00	1.18	0.83							0.00	.962
Closed	Masseter muscle	CP	13	1.62	0.80	3.34	2.05	6.30	.020	6.16	.022	33.35	<.001	14.32	.001
		Control	10	0.41	0.23	0.40	0.23							0.00	.985
	Digastric muscle	CP	13	3.88	3.51	4.84	2.86	1.97	.175	2.47	.131	10.04	.005	5.10	.035
		Control	10	1.17	0.98	1.23	0.86							0.01	.912

CP: athletes with CP

Table.3 COG values of athletes with CP wearing and not wearing a CMG

				Without CMG		With CMG		CMG× Group		CMG		Group		Simple main effect	
Eyes	COG values	Group	N	Mean	SD	Mean	SD	F	*p*	F	*p*	F	*p*	F	*p*
Open	TA	CP	13	885.18	994.82	491.64	206.82	1.91	.180	2.09	.163	5.14	.030	4.60	.044
		Control	10	274.73	127.63	265.73	124.24							0.00	.966
	TL	CP	13	827.18	244.60	698.19	168.93	4.85	.040	4.64	.043	10.11	.010	10.91	.003
		Control	10	536.46	133.77	537.94	141.67							0.00	.974
Closed	TA	CP	13	1264.68	1461.37	735.57	621.37	3.34	.080	3.40	.079	4.00	.060	7.75	.011
		Control	10	339.47	195.70	337.2	187.31							0.00	.992
	TL	CP	13	1047.65	352.20	815.85	264.53	6.14	.020	5.52	.029	6.47	.020	13.40	.001
		Control	10	669.34	206.95	675.46	182.93							0.01	.933

CP: athletes with CP

Table.4 Masticatory muscle activity during gait of athletes with CP wearing and not waring a CMG

Muscle	Group	N	Without CMG		With CMG		CMG× Group		CMG		Group		Simple main effect	
			Mean	SD	Mean	SD	F	*p*	F	*p*	F	*p*	F	*p*
Masseter muscle	CP	9	2.91	1.95	4.38	2.96	6.95	.018	8.65	.010	7.84	.013	15.56	.001
	Control	9	1.27	0.71	1.35	0.83							0.05	.832
Digastric muscle	CP	9	6.07	2.92	8.54	4.32	3.86	.067	5.87	.028	9.12	.008	9.62	.007
	Control	9	3.06	2.13	3.32	2.71							0.11	.749

CP: athletes with CP

Table.5 Gait sway of athletes with CP wearing and not waring a CMG

Gait values	Group	N	Without CMG		With CMG		CMG× Group		CMG		Group		Simple main effect	
			Mean	SD	Mean	SD	F	*p*	F	*p*	F	*p*	F	*p*
Lateral sway ratio	CP	9	0.85	0.27	0.93	0.23	2.12	.165	3.55	.078	1.27	.277	5.58	.031
	Control	9	1.01	0.20	1.02	0.23							0.09	.766
Longitudinal sway ratio	CP	9	1.17	0.24	1.23	0.20	3.30	.088	0.14	.710	8.92	.009	2.41	.140
	Control	9	1.56	0.27	1.52	0.26							1.04	.324
Gait smoothness	CP	9	5.29	3.12	5.49	3.40	0.02	.897	0.73	.406	0.01	.931	0.26	.616
	Control	9	5.37	2.40	5.64	2.06							0.49	.496
Gait levelness	CP	9	0.49	0.31	0.48	0.35	0.50	.488	1.00	.333	4.69	.046	0.04	.840
	Control	9	0.27	0.12	0.22	0.13							1.46	.245
Symmetry of lower body	CP	9	0.60	0.23	0.66	0.22	0.29	.600	7.15	.017	3.82	.068	5.15	.037
	Control	9	0.79	0.17	0.83	0.17							2.29	.150
Symmetry of upper body	CP	9	0.38	0.16	0.43	0.24	0.03	.857	4.35	.053	44.88	<.001	1.81	.197
	Control	9	0.84	0.09	0.90	0.07							2.58	.128

CP: athletes with CP