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Technical Article

Effects of glucose Ramune candy ingestion on concentration during esports play and cognitive function

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Abstract
This study aimed to determine the effects of glucose (Ramune candy) ingestion on cognitive function during esports mediation and concentration during gameplay. The participants were 20 healthy male students who did not play games usually (mean age ± 19.85, standard deviation = 0.96). The experimental design was a randomized, double-blind, placebo-controlled crossover study. The results showed that the ingestion of Ramune candy significantly improved cognitive test scores before and after gameplay. During the esports gameplay, the power percentage of sensorimotor rhythm (SMR, 10-11.75 Hz) waves was significantly higher in the Ramune candy condition than in the placebo condition at 25 to approximately 28 min after the ingestion. These results indicate that the ingestion of Ramune candy effectively maintains a relaxed yet concentrated state during cognitively loaded esports gameplay.

Keywords: Glucose; Ramune candy; Esports; Cognitive function; Trail making test.

1. Introduction

The effects of digital games on cognitive functions are increasingly being examined for gamers of all ages. Anguera et al. (2013) reported that a customized racing game for older adults increased their cognitive abilities. Green and Bavelier (2003) also examined the training effects of digital games on young people and found that performance on an attention test improved. Thus, the number of studies investigating the relationship between digital games and cognitive functions has increased over the years.

One possible reason for this is the rise of esports: the esports market is growing every year (Gough, 2021) and with it the gamer population. Wijman (2020) had estimated it to grow to approximately 3.1 billion by the end of 2020. A large portion of the gamer population comprises light gamers and non-gamers whose gaming skill level is not high. Therefore, promoting research targeting novice gamers is vital for developing gaming research. There are many different genres of esports. Campbell, Toth, Moran, Kowal, and Exton (2018) point out that when examining the effects of gaming, it is necessary to distinguish between the video game genres being played and the evidence of its effects. Furthermore, the participants' gaming skill level and experience need to be uniform.

Games in the racing genre are easier for novice gamers to engage in, and they require less time to learn than the multiplayer online battle arena (MOBA) genres. Additionally, the race mode, where players compete with other cars, requires sustained attention, cognitive flexibility, inhibitory control, and other cognitive abilities because the players must operate the steering wheel and pedal, and constantly keep track of their positions in relation to many enemies. Therefore, this study employed a game in the racing genre and targeted novices with low game skill levels.

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Furthermore, recent research on the relationship between nutrition and esports has examined the effects of energy drink consumption on attention and reaction time during esports play (Thomas, Rothschild, Earnest, & Blaisdell, 2019). Adequate glucose supplementation for cranial nerve activity may help maintain optimal brain function levels. Underlying this theory is the physiological role of glucose in the brain through the biosynthesis of neurotransmitter precursors and the production of adenosine triphosphate, which is fundamental to neuronal and non-neuronal cell maintenance. Researchers have typically observed an increase in blood glucose concentrations after ingesting glucose-rich substances and a concomitant increase in performance on cognitively demanding tests (Gold, Vogt, & Hall, 1986; Kennedy & Scholey, 2000; Sünram-Lea, Foster, Durlach, & Perez, 2001). Many of these studies have used study designs that measure blood glucose and cognitive function test scores as outcomes and have not examined the relationship between glucose intake and gameplay. Thus, by examining the effects of glucose ingestion on cognitive function in non-gamers who do not regularly play esports, and when gameplay intervenes with cognitive load, it may be possible to generalize the results to improve efficiency in various tasks in daily life.

In addition to evaluating the effects of glucose ingestion on cognitive function through tasks performed pre-post, it is also important to focus on the physiological state of gamers during esports play and understand the kind of changes that occur in the related indices. In support of this hypothesis, Nicholson, McNulty, and Poulus (2020) pointed out that there is limited literature on physiological investigations during digital gameplay. It has been reported that the human state of mind is supported by the brain activity (Musha, Terasaki, Haque, & Ivamitsky, 1997), and electroencephalogram (EEG) indicators can estimate psychological states (Lee & Hsieh, 2014). Lim, Yeo, and Yoon (2019) measured the EEG of college students while playing "League of Legend," an MOBA genre game, and reported an increased power ratio of the beta waveband, reflecting selective concentration in the frontal lobe. Hagiwara, Akiyama, and Takeshita (2019) also compared the concentration level extracted from the EEG of college students before and during a soccer game they played and found an increased power ratio of the beta waveband during the game, indicating a significantly higher level of concentration.
Thus, while a few studies have examined the relationship between cognitive function before and after gameplay and concentration extracted from EEG, no study addresses whether glucose ingestion causes changes in conditions during cognitively demanding esports playing. We employed EEG to examine physiological indices during esports play, following the previous studies.

Based on the aforementioned, this study examined the effects of glucose ingestion on cognitive function when mediated by the cognitively loaded variable of gameplay, using the pre–post cognitive test method. Furthermore, we aimed to determine the effects of glucose ingestion on physiological indices using a method to estimate emotions from EEG data during gameplay.

2. Methods

2.1. Participants

The experimental participants were 20 healthy male university students who did not have memory disorder disease symptoms and were not undergoing pharmacological treatment for any disease (age: 19.85 ± 0.96 years, height: 171.40 ± 4.84 cm, bodyweight: 63.90 ± 6.02 kg, mean value ± *SD*). All participants were non-gamers with less than one hour of gameplay per week, excluding the time spent playing social networking games on smartphones.

2.2. Procedures

The Institutional Review Board of Kyushu Sangyo University approved this study (No. 2021-00002, May 20, 2021). This study used a fizzy type of candy (hereafter referred to as Ramune candy). The effects of Ramune candy ingestion were evaluated in this randomized, crossover, double-blind, placebo-controlled study. Participants performed two experiments at a 2-week interval. Two experimental conditions were prepared: a Ramune confectionery ingestion condition and placebo condition. The details of the experimental procedure are shown in Figure 1. Participants first entered the experimental room and answered a questionnaire about their demographics and gameplay experience. They were then asked to sit in a chair and rest with their eyes open for 5 min to neutralize their mind state. An EEG was attached and signals were measured for 2 min to assess the baseline. Later, two types of the trail making tests (TMT-A and TMT-B) were performed as cognitive tasks. After completing the TMT task (Pre), participants were instructed to ingest 120 mL of mineral water and a Ramune candy (or placebo candy) within 5 min. They were then seated at the car racing gameplay seat, and the game rules were explained to them. The race time was measured 25 min after the gameplay started. The gameplay time of the participants was 181.46 ± 5.02 s (mean ± *SD*). The EEG was continuously measured from the beginning to the end of the gameplay, immediately after which the EEG was removed and the TMT task (Post) performed.

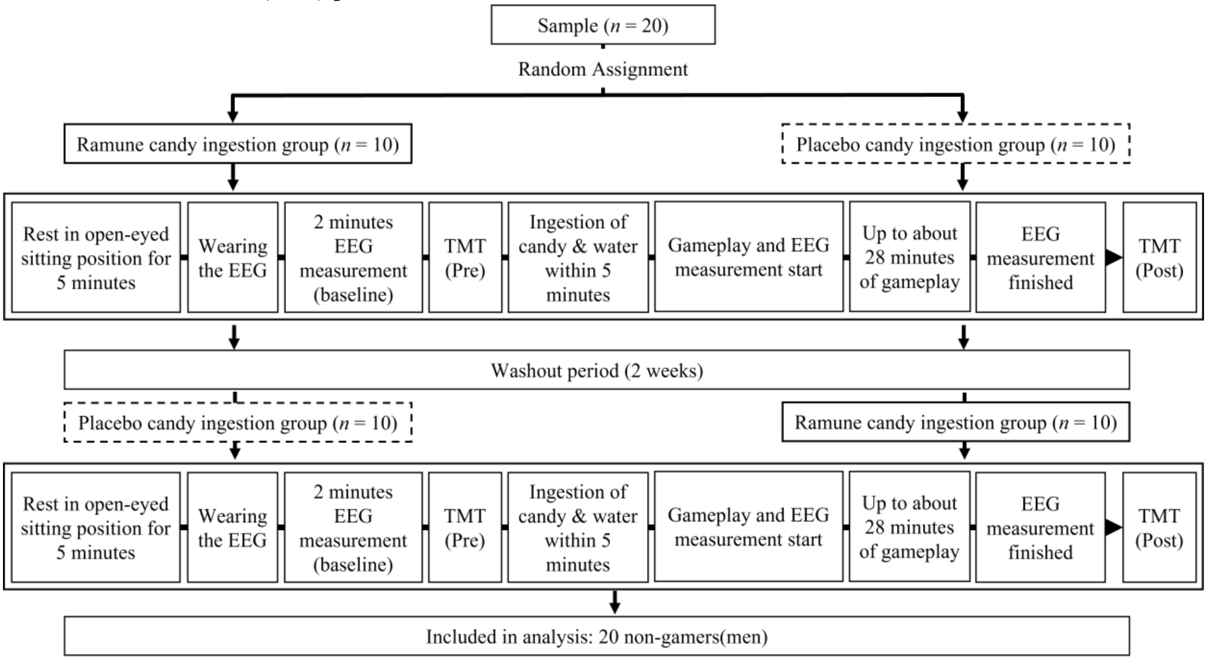

Figure 1. Study design and experimental protocol.

2.3. Test product

This study used a fizzy type of Ramune candy as a test product (Morinaga & Co., Ltd., Tokyo). A 29 g per serving Ramune candy contained 90% hydrous crystal glucose by weight. For the placebo, we replaced the glucose in Ramune candy with erythritol to make it indistinguishable in appearance and flavor.

2.4. Cognitive tasks

In this study, we employed the TMT, which reflects a combination of multiple cognitive functions (Newby, Hallenbeck, & Embretson, 1983; Kortte, Horner, & Windham, 2002). TMT is a cognitive task measuring spatial attention-based visual search ability, working memory, distributed attention, cognitive flexibility, sustained attention, and cognitive processing speed. We used the Japanese version of TMT developed by Ishida and Yoshida (2014), which can be used on personal computers and tablet devices. The participants worked on two types of tests, Part-A and Part-B, and were given instructions and practice trials before beginning the tests. Part-A consisted of 25 numbers, and Part-B consisted of 13 numbers and 12 hiragana characters (i.e., both tests consisted of 25 stimuli). In Part-A, the participants pressed the numbers 1–25 (randomly placed on the screen) in order using finger touch. We measured the time it took to press all the numbers. In Part-B, the participants alternately pressed the numbers and hiragana characters (randomly placed on the screen). Here, we measured the time it took to reach the number 13.

2.5. Adopted game and driving simulator

This study used a racing game in the esports genre called Gran Turismo Sport (Sony Interactive Entertainment Inc., 2017). This game is one of the most competitive esports titles and has been used for the Olympic Virtual Series-Motorsports event. The experiment used a fixed simulator consisting of a BenQ XL2430T, 24-in gaming monitor (at 144 Hz, 1,920 × 1,080 resolution), distance-adjustable gaming chair (Playseat Evolution Alcantara, Netherlands), and steering wheel game controller (Logitech G29-LPRC-15000d, Logitech, USA).

2.6. Evaluation of affect during gameplay using EEG data

A conventional EEG can measure signals from multiple sites but requires much time for wearing and preparation. Furthermore, wearing an EEG device can cause a strong tightening sensation in the scalp. The left frontal lobe is considered a suitable region for obtaining human psychological states as it is less noisy because of head hair (Sakamoto, Sakata, Inoue, & Urahama, 2006). Additionally, the EEG obtained from Fp1 is suitable for estimating human interests (Negishi, Dou, & Mitsukura, 2011). For these reasons, we chose Fp1 (left frontal lobe) as the measurement site, as defined by the international 10-20 method. Methods to standardize electrode placement were studied by H.H. Jasper, resulting in the definition of the 10-20 electrode system (Jasper, 1958). Karlık and Hayta (2014) point out that EEG signals are generated because of neural activity and can be distinguished by their frequency range. This study defined the effective frequency bands, and alpha waves (8-10 Hz), sensorimotor rhythm [SMR] waves (10-11.75 Hz), and beta waves (13-29.75 Hz). Alpha waves indicate relaxation (Chen, Ren, KIM, & Machi, 2000). Beta waves are a frequency band of brain waves extracted during concentration in an open-eyed active state (Friel, 2007; Heinrich, Gevensleben, & Strehl, 2007) and refer to the concentration of processing information that is selectively received. SMR waves are SMRs, which are a frequency range of brain waves that appear during psychological states of relaxation and concentration (Heinrich et al., 2007).

For EEG measurement and analysis, we used a banded simple EEG meter (NeuroSky, Tokyo, Japan) with an EEG signal acquisition chip and a Sports KANSEI (Littlesoftware Inc, Tokyo, Japan) application that records the acquired EEG data on a smartphone and converts it into sensitivity values from 0 to 100 (higher values indicate a higher degree of superiority). First, the potential differences obtained from the reference electrodes on the forehead of the left frontal lobe (Fp1) and the left earlobe were amplified by the circuitry in the device, then numerically processed, digitized at 512 samples/s, and processed by the Hanning window. Then, the fast Fourier transform performed the power spectrum analysis. The sum of the power in each frequency band was calculated from the data obtained, and a relative value showed the ratio of the total power. As the obtained EEG data had different frequency bands, the following equation was used as the standard for analysis following the method of Hagiwara, Mankyu, Tsunokawa, Matsumoto, and Funamori (2020). According to Eq. (1), the average value of x-wave power P_x was calculated using the power V_f of the EEG at frequency f [Hz]. For example, when $x = \beta$, F^x_{max} is assigned 29.75 Hz and F^x_{min} is 13 Hz. Next, the sum of the power means for each frequency band (P_{sum}) was calculated using Eq. (2). Finally, the ratio (R_x) included in the total power of the frequency band to be sought was calculated using Eq. (3).

$$P_x = \sum_{f=F^x_{min}}^{F^x_{max}} V_f/(F^x_{max} - F^x_{min} + 1) \qquad (1)$$

$$P_{sum} = P_\delta + P_\theta + P_\alpha + P_\beta \qquad (2)$$

$$R_x = P_x/ P_{sum} \qquad (3)$$

2.7. Analysis

To compare the changes in cognitive function before and after gameplay between the Ramune candy and placebo ingestion conditions, the pre–post change in TMT score (post-time–pre-time) was analyzed using the paired t-test. Resting-state EEG data were compared between the Ramune candy and placebo ingestion conditions using the paired t-tests. Subsequently, the change in EEG data at rest and during gameplay for each condition was calculated and analyzed using a paired t-test for EEG data comparison. IBM SPSS Statistics software (version 28.0) was used for all statistical analyses. The significance level was set at <10% for a significant trend and <5% for a significant difference. Furthermore, the effect size of Cohen's d index (d) was calculated using unbiased variance to estimate the population value.

3. Results

3.1. Effects of Ramune candy ingestion on cognitive function

The amount of change in performance on the cognitive task is shown in Figure 2. For the TMT-A, the Ramune condition (M = −4.08, SD = 5.29) showed a significant decrease in time compared with the placebo condition (M = −0.57, SD = 5.25) ($t_{(19)}$ = 1.83, p = 0.08, d = 0.41) (Figure 2a). However, there was no significant difference between the conditions regarding TMT-B ($t_{(19)}$ = 0.67, p = 0.51, d = 0.15) (Figure 2b).

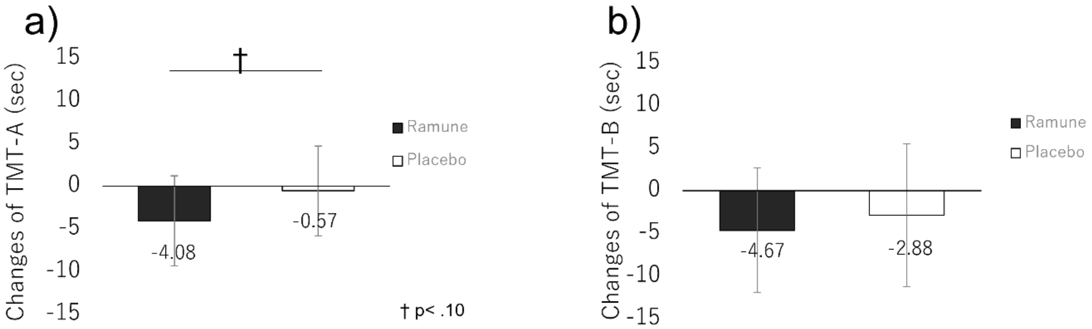

Figure 2. Comparison of the amount of change in TMT-A and TMT-B scores before and after gameplay between the Ramune and placebo conditions. The error bars represent the standard deviation of the mean, † p< .10 between conditions.

3.2. Comparison of EEG data during baseline between the Ramune and placebo conditions

A comparison of power percentages in the alpha, beta, and SMR wavebands at rest between the Ramune and placebo conditions, respectively, revealed no significant differences in power percentages in all EEG bands (Table 1).

Table 1

Comparison of EEG at baseline between the Ramune and placebo conditions.

Type of brain wave	***Ramune condition*** (*n*=20) *M*(*SD*)	***Placebo condition*** (*n*=20) *M*(*SD*)	***t* (19)**	***p***	**[95% CI]**	**Effect size Cohen's *d***
Alpha	31.83(13.04)	33.26(9.39)	0.40	0.69	[-5.98, 8.84]	0.09
Beta	28.42(15.60)	30.30(12.77)	-0.42	0.68	[-11.25, 7.48]	-0.09
SMR	51.14(9.64)	50.84(9.63)	-0.10	0.92	[-6.54, 5.93]	-0.02

Note. *M*= mean; *SD*= standard deviation; *N* = 20; 95% Cl = 95% confidence interval.

3.3. Comparison of EEG data during gameplay between the Ramune and placebo conditions

To examine time-series changes, the amount of change in percent power of alpha, beta, and SMR waves for EEG data at rest and during gameplay were compared for the Ramune and placebo conditions, respectively.

First, the percent power of alpha, beta, and SMR waves at 10 and 20 min after ingestion of the test products were compared in the Ramune and placebo conditions, respectively. No significant differences were found in all EEG bands as in the baseline (resting) results. The same analysis was then performed using EEG data from 25 min after gameplay to the end of the race (approximately 28 min). The results showed no significant difference between conditions in the amount of change in the power fraction of the beta wave (Ramune condition, M = 0.38, SD = 15.18; placebo condition, $M = -5.47$, SD = 15.88) ($t_{(19)} = -1.24$, p = 0.23, $d = -0.28$) (Figure 3b). However, a significant difference was found in the power fraction in the alpha waveband, with a higher change in power fraction in the Ramune condition (M = 3.78, SD = 13.13) than in the placebo condition ($M = -3.38$, SD = 8.38) ($t_{(19)} = -2.03$, p = 0.06, $d = -0.45$) (Figure 3a). Similarly, a significant difference was found in the power fraction in the SMR waveband, with a greater change in power fraction in the Ramune condition (M = 5.84, SD = 9.82) than in the placebo condition ($M = -2.98$, SD = 8.33) ($t_{(19)} = -3.15$, p = 0.005, $d = -0.70$) (Figure 3c).

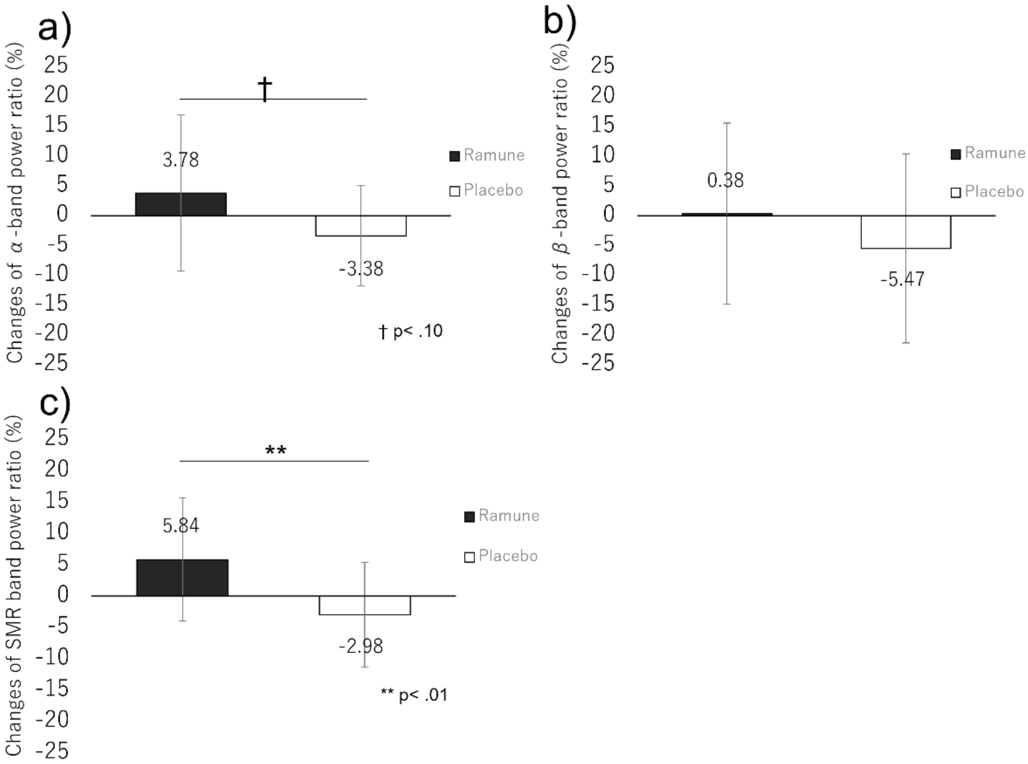

Figure 3. Changes of EEG power ratio 25 min after Ramune or placebo candy ingestion (%). The data were analyzed after 25 min elapsed to the end of the race (approximately 28 min). The error bars represent the standard deviation of the mean, † *p*< .10, ** *p*< .01 between conditions.

4. Discussion

This study aimed to determine the effects of glucose candy ingestion on cognitive function when mediated by playing a racing game in adult males in their 20s who rarely played esports games. A significant reduction in TMT-A execution time was observed in the Ramune condition, and the effect size was medium. These results indicated that glucose ingestion may be effective in improving information processing speed and sustained attention, among other cognitive functions. Similar results were reported in a study of female college students (Benton, Parker, & Donohoe, 1996). In addition, as shown by Inagaki et al.'s study (2020), glucose intake may have caused an increase in blood glucose levels and improved cognitive function. However, it is also possible that the gameplay itself had a positive effect, improving cognitive function. Future studies should examine the synergistic effects of these variables.

No significant differences were found in the power percentages of all EEG bands for the EEG data at rest, which suggests that the EEG device and the Sports KANSEI algorithm used in this study were reliable. A time-series comparison of EEG during gameplay showed that the power percentage of beta waves 25 min after the start of the game (when race time data were collected) had no significant change between conditions. There was no change observed in the beta wave power ratio between conditions, compared with the alpha wave and SMR wave power ratio, likely due to the large SD, which was influenced by the individual difference factor due to the data variability. However, 25 min after the game started, the alpha and SMR waves were significantly higher in the Ramune condition than in the placebo condition. Ueda, Imamura, and Ibaraki (2021) stated that it is easy to have a sense of *flow* or *being in the zone* when SMR waves are generated. Csikszentmihalyi (1990) described the ideal or optimal level of engagement as *flow*, a state of being immersed in the task that one forgets the passage of time. Similarly, Chen (2007) and Ryan, Rigby, and Przybylski (2006) describe it as *being in the zone* and *total immersion*, respectively. Thus, the results suggest that glucose ingestion effectively maintains a relaxed yet focused state during cognitively demanding gameplay. The reason for this may be that the appropriate amount of glucose ingestion for maintaining optimal brain function in normal individuals is approximately 25 g (Inagaki et al., 2020), and the test food used in this study met this requirement. As the balance between relaxation and concentration is expected to impact game performance significantly, it is necessary to examine the impact of glucose ingestion on game performance by game skill. Another limitation of this study is that we have not been able to obtain and evaluate data on differences due to game content and player skill level. Therefore, the effects of different characteristics on the power fractions of the various frequency bands need to be examined in more detail. From the aforementioned, it can be inferred that glucose ingestion enhances some cognitive functions through its effects on brain activity. However, considering the many unexplained details of the mechanism, future research is warranted.

5. Conclusions

This study aimed to determine the effects of glucose intake on cognitive function measured before and after gameplay in non-gaming adult men. The effects of glucose ingestion improved information processing speed and sustained attention. Additionally, analysis of EEG data during gameplay revealed that the power percentage of SMR waves around the 25-min mark was higher in the glucose ingestion condition than in the placebo condition, indicating that glucose ingestion may help maintain a high state of extreme concentration during cognitively demanding esports play. Future studies may examine the effects of glucose ingestion in esports and cognitively demanding tasks such as study and work.

Author Contributions

Conceptualization, R.F., G.H.; methodology, R.F., G.H., H.I.; software, R.F.; validation, R.F.; formal analysis, R.F., G.H.; investigation, R.F., G.H.; resources, R.F., H.I.; data curation, R.F., G.H.; writing—original draft preparation, R.F.; writing—review and editing, R.F.; visualization, R.F.; supervision, G.H.; project administration, R.F., H.I.; funding acquisition, G.H., H.I.; All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted according to the Declaration of Helsinki and approved by the Institutional Review Board of Kyushu Sangyo University (No.2021-00002, May 20, 2021).

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

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