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Effects of regular and mastic chewing gum on alertness, mood, heart rate and EEG activity in adolescents: a pilot study

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Abstract
Chewing gum has been associated with changes in alertness, mood, and cognitive performance. Natural mastic gum (*Pistacia lentiscus* resin) differs from commercial chewing gum in composition and texture, but its neurophysiological effects have not been previously explored. This pilot study aimed to assess the feasibility of measuring heart rate, mood, alertness, and electroencephalographic (EEG) activity during chewing, and to explore potential differences in these attributes between regular sugar-free gum and natural mastic gum in adolescents. Thirty healthy 15-year-old students were randomly assigned to chew either regular sugar-free gum or natural mastic gum for 3 minutes. Heart rate was recorded before and during chewing. EEG activity (alpha, beta, and theta rhythms) and derived mental state indices were recorded at three time points using a wearable EEG headband. Mood and alertness were assessed using a validated Visual Analogue Scale (Global Vigor and Affect). Non-parametric statistical tests were used to determine any differences due to small sample size and non-normal distributions. Chewing gum was not associated with significant changes in heart rate. Global Vigor increased during chewing in the total sample, reaching statistical significance within the mastic gum group, although between-group differences were not significant. Exploratory EEG analyses showed changes in alpha, beta, and theta rhythms during and after chewing, particularly in the mastic gum group; however, large inter-individual variability and multiple comparisons limited interpretation. Mental state indices derived from EEG showed no consistent changes. This pilot study demonstrates the feasibility of combining subjective and wearable EEG measures to examine the acute effects of chewing gum in adolescents. Chewing was associated with short-term changes in alertness and EEG activity, but evidence for differential effects between gum types remains preliminary. Larger, controlled, and blinded crossover studies are required to confirm these findings and clarify underlying mechanisms.

Keywords
Chewing gum, Mastic gum, Alertness, Concentration, Heart rate, Brainwave, Brainbit, Mental state, Mood state, Cognitive performance

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1. Introduction

Anxiety, fatigue, mental and mood disorders have been associated with the demanding modern life and are increasing particularly among children and adolescents (1). In 2020–2021, more than 60% of students met criteria for one or more mental health problems, such as depression, anxiety, eating disorders, suicidal ideation (2). Cognitive fatigue, the deterioration in the ability to think effectively and maintain focus is common even among students (3). Recommendations to avoid cognitive fatigue include proper sleep, lighter schedules, exercise and relaxation by yoga, deep breathing, massage and aromatherapy (4).

Chewing gum is a soft, cohesive substance designed to be chewed without being swallowed. Chewing gum is composed of gum base, sweeteners, softeners, plasticizers, flavors, colors, and, typically, a hard or powdered polyol coating. The ancient Greeks chewed mastic gum, a resin that comes from the plant *Pistacia lentiscus* var. chia, which is cultivated in countries around the Mediterranean Sea and particularly in the southern part of the island of Chios. Mastic gum has numerous biomedical and pharmacological properties including eradication of bacteria and fungi that may cause peptic ulcers, tooth plaque formation and malodor of the mouth and saliva, reduction of symptoms of autoimmune diseases, protection of the cardiovascular system by effectively lowering the levels of total serum cholesterol, anticarcinogenic effects in laboratory experiments, and improvement of dyspepsia (5).

Chewing gum has been shown to reduce stress, fatigue and led to a more positive mood (6-11). Moreover, chewing gum seems to improve cognitive functions, such as attention, learning, memory, work and intellectual performance (10, 12-20). In a recent study by Hamada *et al.* (21), gum-chewing during walking increased walking distance, speed, heart rate and energy use. Positive effects of chewing gum on mood, relaxation and concentration have been demonstrated. However, the effects of natural mastic gum have not been investigated before. The aim of this pilot study was to assess the feasibility of measuring physiological, neurophysiological, and subjective responses to chewing gum in adolescents, and to explore potential differences between regular sugar-free gum and natural mastic gum. The study was designed to generate preliminary effect size estimates and inform the design of future controlled trials.

2. Methods

Thirty mentally and physically healthy 15-year-old individuals, 15 males and 15 females from the school environment of the author were recruited for the study. The participants were randomly assigned into two groups by using a number generator (22). The first group chewed a regular sugar-free gum (Dentyne ICE spearmint flavour, Pefretti Van Benelux B.V., Breda, The Netherlands) and the second group chewed a sugar-free natural mastic gum (ΕΛΜΑ, product of the Chios gum mastic growers´ association, Chios, Greece). Written informed consent was obtained by participants´ guardians. Participants were also given written information. The experiment took place in a quiet room with as standardized conditions as possible.

Upon the initiation of the experiment, participants were provided a Visual Analog Scale (VAS) for mood registration (VAS1). The VAS used was the pencil-and-paper version of Global Vigor and Affect instrument, including registrations for tiredness/arousal, sadness/joy (23) (Appendix 1). After the completion of VAS1, heart rate was recorded for 20 seconds (HR1) by using the Measure Heart Rate application on a mobile phone (Chenzhen Chenxi Information Technology Co. Ltd, Shenzhen) (24). Following, the BrainBit Headband (BrainBit Inc., Brooklyn, NY 11232), a non-medical device for simplified electroencephalography (EEG) was placed on the participant (25). The device offers a simple way for non-professionals to follow brain activity and mental state by recording alpha, beta and theta brain rhythms, as well as the principal mental state: concentration, regular activity or relaxation (EEG Waves App) (26). EEG outcomes were considered exploratory due to the use of a non-medical wearable device and the potential influence of chewing-related muscle activity. Brainwave activity was recorded for 60 seconds (BB1). A regular chewing or a mastic gum was then given to the participant, who started chewing. Ten seconds after the initiation of chewing, a new BrainBit recording was taken for 90 seconds while the participant was chewing (BB2). Always under chewing and ten seconds after the end of BB2 a new heart rate measurement was taken for 20 seconds (HR2). The participant was then asked to keep the chewing gum in his/her mouth, but without chewing this time. Another BrainBit record was taken for 30 seconds (BB3). Finally, the participant was asked to simultaneously start chewing again and fill another VAS (VAS2) under chewing for 60 seconds (Figures 1, 2 and 3).

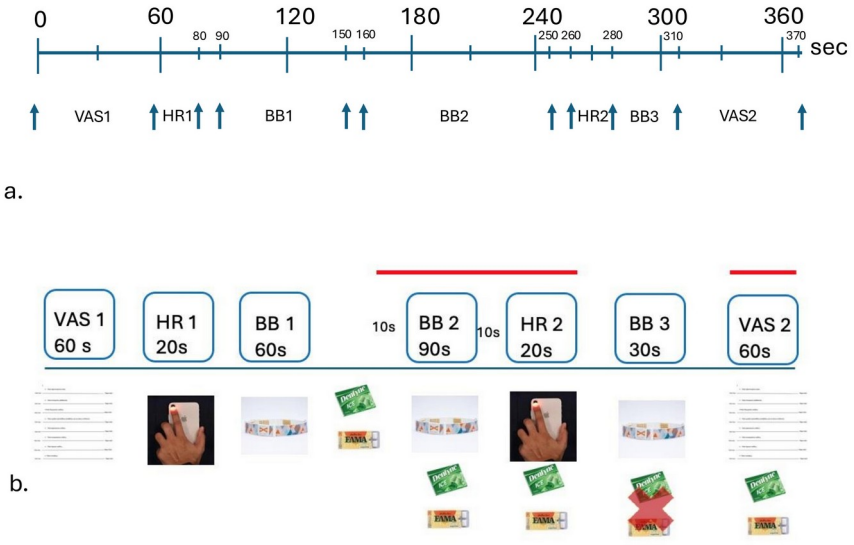

Figure 1. a. Timeline of the experiment and **b**. Illustrated experimental design flow; VAS, Visual Analogue Scale; HR, Heart Rate measurement; BB, BrainBit Headband measurement. Red line indicates active chewing.

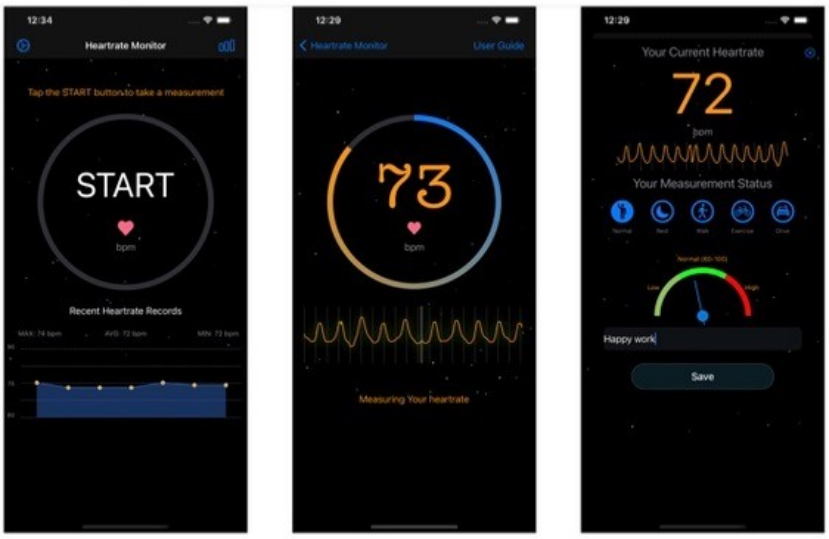

Figure 2. Heart rate registration using the Measure Heart Rate Application

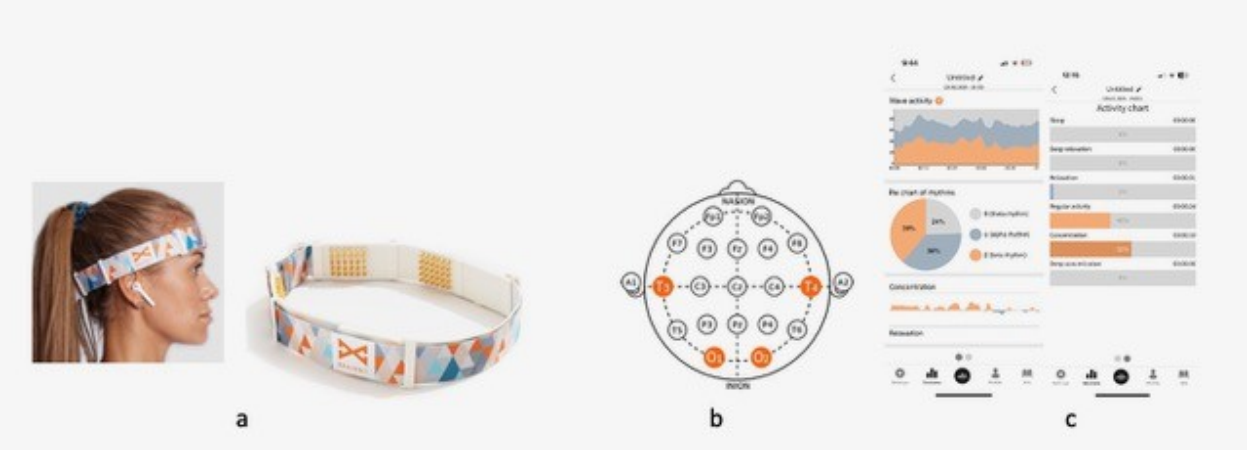

Figure 3. **a.** BrainBit Headband. The headband amplifies and digitizes the received signal and transmits it via the Bluetooth LE protocol to a computer, smartphone or tablet. **b.** Four dry EEG electrodes are included in the appliance: O1 and O2 placed in occipital region record alpha rhythm, an indicator of relaxation, whereas T3 and T4 electrodes placed in the temporal region record beta rhythm, which is an indicator of the level of concentration or attention. **c.** EEG Waves App software application was used on a mobile phone connected by Bluetooth to the BrainBit Headband, to extract recordings concerning the three major brain waves, alpha, beta and theta. The principal mental state was also registered.

Descriptive statistics, the non-parametric Wilcoxon Signed-Rank test for intragroup comparisons during the different timepoints and the non-parametric Mann-Whitney U test for intergroup comparisons were performed using JASP statistical program. Wilcoxon Signed-

Rank tests were performed for the total sample and each experimental group separately, while the effect of gum type and gender was evaluated on the differences among various time points for all variables with Mann-Whitney U tests and Kruskal-Wallis tests.To control for multiple comparisons, Bonferroni correction was applied separately within predefined families of related outcomes. Subjective (Global Vigor, Global Affect), physiological (Heart Rate), and EEG-derived outcomes were treated as distinct families. EEG frequency band analyses and EEG-derived mental state indices were considered exploratory. Corrected significance thresholds were calculated by dividing $\alpha = 0.05$ by the number of comparisons within each family. The corrected α was hence 0.0167 for Global Vigor and Heart Rate (number of comparisons=3) and 0.0056 for EEG frequency band analysis and EEG-derived mental state indices (number of comparisons=9).

To evaluate measurement uncertainty and intrinsic EEG variability, BrainBit measurements were performed 3 times on 3 control subjects (without interventions), allowing 20 minute-intervals between measurements. For each variable, Standard Deviation (SD) or variance was calculated across the three measurements for each individual, together with the mean SD-value for the three control subjects.

As a pilot study, no formal sample size calculation was performed. The study was intended to explore feasibility, variability, and potential signal direction rather than to provide confirmatory evidence of efficacy.

3. Results

Given the exploratory nature of the study and the large number of comparisons, results should be interpreted as hypothesis-generating.

A total of 30, 15-year-old students, grouped according to the type of gum (Regular (Type 0): 8 males, 7 females; Mastic (Type 1): 7 males, 8 females) completed the experiment without particular difficulties. Heart rate was not affected by chewing gum, neither for all participants nor for each type of gum separately. The same applied for the Global Affect (GA) measurements. Global Vigor (GV) was significantly increased during chewing for the total sample (P=0.01, Z= -2.75, Effect Size= -0.57, CI= -0.79, -0.24) and for the Mastic gum group when examined alone, while it was not altered significantly for the Regular gum group.

3.1 Heart rate

3.1.1 *Within TYPE (group) comparisons*

Preliminary assumption checks indicated violations of normality (Shapiro–Wilk test, $p < .05$). Therefore, non-parametric tests were used for all analyses. Therefore, a Wilcoxon signed-rank test (Tails: H_1: [After-Before] < μ_0) was performed within groups (comparing beginning and end of chewing for TYPE 0, as well as comparing beginning and end of chewing for TYPE 1). Results of the Wilcoxon Signed-Rank test (Table 1) indicated that for the TYPE 0 student group (regular gum) there was a non-significant decrease in heart rate between before (beginning of chewing) (Mdn = 64 , n = 15) and after (completion of chewing test) (Mdn = 67, n = 15), Z = -0.8, p = 0.793, effect size [reported as r ($Z/\sqrt{N}$)] = -0.2. For the TYPE 1 student group

(mastic gum), even though the median decreased from 67 to 66 (i.e. in the hypothesized direction), this decrease was not statistically significant, with Z = −1.1, p = 0.871, effect size= −0.3, indicating that the data did not provide sufficient evidence to support the hypothesis that chewing mastic gum correlated with a decrease in heart rate after 3 minutes.

Table 1. Within group Wilcoxon signed-rank tests for heart rate (Tails: H_1: [After-Before] < μ_0), n=15

Group	Mdn (Before, After)	Z	*p*	Standardized Effect size
TYPE 0	64, 67	-0.8	0.793	-0.2
TYPE 1	67, 66	-1.1	0.871	-0.3

3.1.2 *Between TYPE (group) comparisons*

Mann-Whitney U tests (Two Tailed: H_1: TYPE 0 ≠ TYPE 1) were performed to compare heart rates of TYPE 0 and TYPE 1 student groups at the beginning of the chewing test, and at the end of the chewing test. In addition, the difference between the individual values at the beginning and the end of the chewing test were also compared between TYPE 0 and TYPE 1 groups (Table 2). There was no significant difference between the heart rate between the two groups at the beginning of the chewing test (*Mdn* = 64 (TYPE 0), 67 (TYPE 1), U=95.5, *Z* = 0.7, *p* = 0.493, effect size = 0.1). There was also no significant difference between the heart rate between the two groups at the end of the chewing test (*Mdn* = 67 (TYPE 0), 66 (TYPE 1), U=108.0, *Z* = 0.2, *p* = 0.868, effect size = 0.03). The Mann-Whitney U test also indicated no significant difference in the heart rate change between the regular gum chewing group (TYPE 0) and the mastic gum chewing group (TYPE 1), ((*Mdn* = 5 (TYPE 0 difference), 1 (TYPE 1 difference)), U=106.0, *Z* = -0.2, *p* = 0.803, effect size = -0.04)

Table 2. Between group Mann-Whitney U tests for heart rate (Two Tailed: H_1: TYPE 0 ≠ TYPE 1), n=15

Time	Mdn (Type 0, Type 1)	U	Z	*p*	Standardized Effect size
TYPE 0 and TYPE 1 (beginning of chewing test)	64, 67	95.5	0.7	0.493	0.1
TYPE 0 and TYPE1 (end of chewing test)	67, 66	108.0	0.2	0.868	0.03
TYPE 0 and TYPE 1 (difference)	5,1	106.0	-0.2	0.803	-0.04

3.1.3 *Gender segregated heart rate (within group)*

A Wilcoxon signed-rank test (Tails: H_1: [After-Before] < μ_0) was performed within groups (comparing beginning and end of chewing for TYPE 0 (males and females separately), as well as comparing beginning and end of chewing for TYPE 1 (males and females separately). Results of the Wilcoxon Signed-Rank test are shown in Table 3. No significant decrease in heart rate;

either for TYPE 0 (regular gum) or for TYPE 1 (mastic gum) was found before and after chewing, regardless of the gender of the student.

Table 3. Within group Wilcoxon signed-rank tests for heart rate (Tails: H_1: [After-Before] < μ_0), n=8 and 7 for Males and Females respectively

Group	Mdn (Before, After)	Z	*p*	Standardized Effect size
TYPE 0 (MALES)	64.5, 71.5	-2.0	0.977	-0.8
TYPE 0 (FEMALES)	64, 66	-0.6	0.289	-0.2
TYPE 1 (MALES)	60, 61	1.2	0.876	0.5
TYPE 1 (FEMALES)	68, 70	0.8	0.780	0.3

3.2 Global Vigor

3.2.1 *Within TYPE (group) comparisons*

A Wilcoxon signed-rank test (Tails: H_1: [After-Before] > μ_0) was performed within groups (comparing beginning and end of chewing for TYPE 0, as well as comparing beginning and end of chewing for TYPE 1). Results of the Wilcoxon Signed-Rank test (Table 4) indicated that for the TYPE 0 student group (regular gum), even though the median increased from 47 to 50 (i.e. in the hypothesized direction, this increase was not statistically significant, with $Z = 1.4$, $p = 0.078$, effect size [reported as r ($Z/\sqrt{N}$)] = 0.4. For the TYPE 1 student group (mastic gum), there was a significant increase in global vigor between before (Mdn = 41 ,n = 15) and after (Mdn = 57 ,n = 15), $Z = 2.4$, $p = .008$, r = 0.6. , indicating that the data provided sufficient evidence to support the hypothesis that chewing mastic gum correlates with an increase in global vigor after 3 minutes.

Table 4. Within group Wilcoxon signed-rank tests for global vigor (Tails: H_1: [After-Before] > μ_0), n=15

Group	Mdn (Before, After)	Z	*P*	Standardized Effect size
TYPE 0	47, 50	1.4	0.078	0.4
TYPE 1	41, 57	2.4	0.008	0.6

3.2.2 *Between TYPE (group) comparisons*

Mann-Whitney U tests (Two Tailed: H_1: TYPE 0 ≠ TYPE 1) were performed to compare global vigor of TYPE 0 and TYPE 1 student groups at the beginning of the chewing test, and at the end of the chewing test. In addition, the difference between the individual values at the beginning and the end of the chewing test were also compared between TYPE 0 and TYPE 1 groups (Table 5). There was no significant difference in the global vigor between the two groups at the beginning of the chewing test (Mdn = 47 (TYPE 0), 41 (TYPE 1), U=92.0, Z = 0.8, p = 0.406, effect size = 0.2). There was also no significant difference in the global vigor between the two groups at the end of the chewing test (Mdn = 47 (TYPE 0), 57 (TYPE 1), U=92.5, Z = -0.8, p = 0.418, effect size = -0.15). The Mann-Whitney

U test also indicated no significant difference in the global vigor change between the regular gum chewing group (TYPE 0) and the mastic gum chewing group (TYPE 1), ((*Mdn* = 5 (TYPE 0 difference), 6 (TYPE 1 difference)), U=96.5, *Z* = -0.6, *p* = 0.520, effect size = -0.12)

Table 5. Between group Mann-Whitney U tests for global vigor (Two Tailed: H_1: TYPE 0 ≠ TYPE 1), n=15

Time	Mdn (Type 0, Type 1)	U	Z	*p*	Standardized Effect size
TYPE 0 and TYPE 1 (beginning of chewing test)	47, 41	92.0	0.8	0.406	0.2
TYPE 0 and TYPE 1 (end of chewing test)	47, 57	92.5	-0.8	0.418	-0.15
TYPE 0 and TYPE 1 (difference)	5, 6	96.5	-0.6	0.520	-0.12

3.2.3 *Gender segregated Global Vigor (within group)*

A Wilcoxon signed-rank test (Tails: H_1: [After-Before] < μ_0) was performed within groups (comparing beginning and end of chewing for TYPE 0 (males and females separately), as well as comparing beginning and end of chewing for TYPE 1 (males and females separately). Results of the Wilcoxon Signed-Rank test are shown in Table 6. No significant alteration in Global Vigor; either for TYPE 0 (regular gum) or for TYPE 1 (mastic gum) was found before and after chewing, regardless of the gender of the student.

Table 6. Within group Wilcoxon signed-rank tests for Global Vigor (Tails: H_1: [After-Before] < μ_0), n=8 and 7 for Males and Females respectively

Group	Mdn (Before, After)	Z	*p*	Standardized Effect size
TYPE 0 (MALES)	48.0, 47.5	-1.1	0.313	-0.4
TYPE 0 (FEMALES)	47.0, 58.0	-1.4	0.204	-0.5
TYPE 1 (MALES)	46.0, 55.0	-1.8	0.090	-0.7
TYPE 1 (FEMALES)	38.5, 58.5	-1.7	0.109	-0.6

3.3 Global Affect

3.3.1 *Within TYPE (group) comparisons*

A Wilcoxon signed-rank test (Tails: H_1: [After-Before] > μ_0) was performed within groups (comparing beginning and end of chewing for TYPE 0, as well as comparing beginning and end of chewing for TYPE 1). Results of the Wilcoxon Signed-Rank test (Table 7) indicated that for the TYPE 0 student group (regular gum), even though the median increased from 80 to 85 (i.e. in the hypothesized direction, this increase was not statistically significant, with $Z = 0.7$, $p = 0.245$, effect size [reported as r ($Z/\sqrt{N}$)] = 0.2. For the TYPE 1 student group (mastic gum), there was a non- significant increase in global affect between before (*Mdn* = 77 ,*n* = 15) and after (*Mdn* = 77 ,*n* = 15), *Z* = 0.9, *p* = 0.191, effect size = 0.2. , indicating that the data did not provide sufficient evidence to support the

hypothesis that chewing mastic gum correlates with an increase in global affect after 3 minutes.

Table 7. Within group Wilcoxon signed-rank tests for global affect (Tails: H_1: [After-Before] > μ_0), n=15

Group	Mdn (Before, After)	Z	*p*	Standardized Effect size
TYPE 0	80, 85	0.7	0.245	0.2
TYPE 1	77, 77	0.9	0.191	0.2

3.3.2 *Between TYPE (group) comparisons*

Mann-Whitney U tests (Two Tailed: H_1: TYPE 0 ≠ TYPE 1) were performed to compare global affect of TYPE 0 and TYPE 1 student groups at the beginning of the chewing test, and at the end of the chewing test. In addition, the difference between the individual values at the beginning and the end of the chewing test were also compared between TYPE 0 and TYPE 1 groups (Table 8). There was no significant difference in the global affect between the two groups at the beginning of the chewing test (*Mdn* = 80 (TYPE 0), 77 (TYPE 1), U=102.5, $Z = 0.4$, $p = 0.693$, effect size = 0.07). There was also no significant difference in the global affect between the two groups at the end of the chewing test (*Mdn* = 85 (TYPE 0), 77 (TYPE 1), U=90.5, $Z = 0.9$, $p = 0.372$, effect size = 0.16). The Mann-Whitney U test also indicated no significant difference in the global affect change between the regular gum chewing group (TYPE 0) and the mastic gum chewing group (TYPE 1), ((*Mdn* = 2 (TYPE 0 difference), 2 (TYPE 1 difference)), U=112, $Z = 0.0$, $p = 1.000$, effect size = 0.0).

Table 8. Between group Mann-Whitney U tests for global affect (Two Tailed: H_1: TYPE 0 ≠ TYPE 1), n=15

Time	Mdn (Type 0, Type 1)	U	Z	p	Standardized Effect size
TYPE 0 and TYPE 1 (beginning of chewing test)	80, 77	102.5	0.4	0.693	0.07
TYPE 0 and TYPE 1 (end of chewing test)	85, 77	90.5	0.9	0.372	0.16
TYPE 0 and TYPE 1 (difference)	2, 2	112	0.0	1.000	0.0

3.3.3 *Gender segregated Global Affect (within group)*

A Wilcoxon signed-rank test (Tails: H_1: [After-Before] < μ_0) was performed within groups (comparing beginning and end of chewing for TYPE 0 (males and females separately), as well as comparing beginning and end of chewing for TYPE 1 (males and females separately). Results of the Wilcoxon Signed-Rank test are shown in Table 9. No significant change in Global Affect; either for TYPE 0 (regular gum) or for TYPE 1 (mastic gum) was found before and after chewing, regardless of the gender of the student.

Table 9. Within group Wilcoxon signed-rank tests for Global Affect (Tails: H_1: [After-Before] < μ_0), n=8 and 7 for Males and Females respectively

Group	Mdn (Before, After)	Z	*p*	Standardized Effect size
TYPE 0 (MALES)	86.5, 85.5	-0.3	0.844	-0.11
TYPE 0 (FEMALES)	79.0, 85.0	-0.9	0.402	-0.34
TYPE 1 (MALES)	77.0, 77.0	-1.1	0.310	-0.41
TYPE 1 (FEMALES)	77.5, 76.5	-0.2	0.916	-0.07

Table 10 presents descriptive statistics for EEG frequency bands and EEG-derived mental state indices across the three recording periods. Considerable inter-individual variability was observed across all EEG measures, particularly for mental state indices, underscoring the exploratory nature of these outcomes. Given the exploratory aim, small sample size, absence of control, unequal EEG recording durations and susceptibility of EEG recordings to chewing-related artifacts, formal hypothesis testing was not performed for EEG outcomes; instead, descriptive statistics were used to characterize variability and inform future study design.

Table 10. Mean values and Standard Deviations, for all Brain Activity variables during the 3 recordings (1,2,3), for all participants, only regular gum chewers and only mastic gum chewers.

Variable	Group	BB1 Mean ± SD	BB2 Mean ± SD	BB3 Mean ± SD
α-rhythm (%)	All	37.91 ± 2.7	36.72 ± 2.7	39.31 ± 2.9
	Regular gum	38.5 ± 2.8	36.8 ± 2.3	38.7 ± 3.2
	Mastic gum	37.3 ± 2.5	36.5 ± 3.1	40.0 ± 2.6
β-rhythm (%)	All	26.5 ± 6.4	23.2 ± 3.5	29.6 ± 6.4
	Regular gum	25.7 ± 6.4	23.2 ± 2.9	28.4 ± 6.9
	Mastic gum	27.4 ± 6.5	23.3 ± 4.1	30.9 ± 5.7
θ-rhythm (%)	All	32.7 ± 6.3	37.3 ± 4.6	28.4 ± 5.6
	Regular gum	32.9 ± 6.7	37.1 ± 3.1	30.3 ± 5.5
	Mastic gum	32.2 ± 6.1	37.4 ± 5.6	26.4 ± 5.1
Mental state: Concentration (%)	All	32.3 ± 25.7	30.6 ± 27.1	22.0 ± 28.8
	Regular gum	20.0 ± 21.6	31.3 ± 29.1	22.4 ± 31.3
	Mastic gum	44.7 ± 24.0	29.9 ± 25.9	21.7 ± 27.0
Mental state: Regular activity (%)	All	54.1 ± 18.8	51.9 ± 22.3	59.8 ± 23.4
	Regular gum	59.9 ± 17.4	53.1 ± 21.7	59.3 ± 26.2
	Mastic gum	48.3 ± 18.8	50.7 ± 23.6	60.3 ± 21.1
Mental state: Relaxation (%)	All	11.7 ± 14.7	14.7 ± 22.5	17.9 ± 19.4
	Regular gum	17.9 ± 14.6	11.8 ± 15.6	19.1 ± 20.0
	Mastic gum	5.4 ± 12.1	17.5 ± 28.0	16.8 ± 19.4

4. Limitations

The present study was conducted as a school project with inevitable limitations, including a small sample size, short experimental duration,

and potential selection bias. Although the experiment was conducted in the same room under similar light and sound conditions, the timing of testing varied, with some participants assessed at the beginning and others at the end of the school day. This variation may have influenced baseline alertness and fatigue levels. The sample size was constrained by school scheduling, and no *a priori* statistical power analysis was performed.

No 'no-chewing' or 'sham-chewing' control condition was included, preventing separation of chewing-specific effects from those related to repeated muscle contraction, time, or task engagement. School scheduling constraints also precluded a crossover design, increasing susceptibility to inter-individual variability and limiting statistical power. Despite random assignment, the small sample size may not have ensured equivalence between groups at baseline, raising the possibility of residual confounding.

Although participants were not explicitly informed of the gum type, sensory differences in taste, texture, and smell may have resulted in partial unblinding. Heart rate was measured using a mobile phone application that has not been formally validated for research purposes. Similarly, the EEG device used (BrainBit Headband) is not a medical-grade or clinically validated instrument, and EEG recordings during chewing are particularly susceptible to contamination from facial and masticatory muscle activity.

In addition, EEG recordings were obtained over unequal time durations across experimental phases, which may have affected the stability and reliability of frequency band estimates and limited the strength of inter- and intra-group comparisons. The large number of exploratory EEG outcomes further increased the risk of Type I error.

Subjective alertness and mood were assessed using a validated pencil-and-paper Visual Analogue Scale (23); however, no objective cognitive performance tasks were included. Finally, the simultaneous use of multiple instruments, active chewing, and questionnaire completion may have increased cognitive load or stress for some participants. Generalizability is further limited by the narrow age range and single-school setting.

5. Discussion

This pilot study explored the acute effects of chewing regular gum and natural mastic gum on heart rate, mood, alertness, and EEG activity in adolescents. The primary contribution of the study lies in demonstrating the feasibility of combining subjective measures with wearable EEG technology in a school setting, while providing preliminary, exploratory observations of chewing-related changes in self-reported alertness and EEG signal behavior.

Measurement variability of the Brainbit was quantified using the within-subject SD obtained by repeated measurements of control subjects. This variability reflects intrinsic EEG fluctuations as well as variability associated with the device's mental-state indices. Observed differences between the two chewing-gum groups were comparable in magnitude to estimated measurement variability, highlighting the need for cautious interpretation.

Heart rate was not altered by chewing gum in the study. This finding is consistent with Allen et al. (18) who found no change in the heart rate while chewing gum during the workday. Other studies, however, support the increase of heart rate during gum-chewing (16, 27). Baseline levels of physical activity and alertness may have influenced cardiovascular responses in the present experiment. Participants were likely physically active prior to testing, and the school schedule did not permit a standardized rest or adjustment period before measurements were obtained. The insignificant change in heart rate is consistent with some prior studies but contrasts with others, highlighting the sensitivity of cardiovascular measures to baseline activity, measurement duration, and methodological factors. Mood ratings showed limited change, likely reflecting high baseline affect and potential ceiling effects in this adolescent sample.

Global Vigor, a self-reported measure of alertness and mental energy, increased during chewing in the overall sample and within the mastic gum group, but not within the regular gum group. This finding suggests a possible association between chewing mastic gum and increased subjective alertness; however, no conclusions regarding protection against mental fatigue or effects on cognitive performance can be drawn from the present data. Several studies have reported associations between chewing gum and increased alertness or task engagement (10, 18). However, the acute effects of natural mastic gum on alertness have not been previously examined in adolescent populations. Global Affect, a measure of mood, did not change meaningfully with chewing. In contrast, a study in Japanese nursing students reported reduced anxiety and fatigue and improved mood following a 14-day chewing gum intervention (28), suggesting that mood effects may depend on intervention duration and context.

Despite the small sample, some differences in induced alertness, as given by Global Vigor and descriptive variations in alpha-band estimates were observed across recording periods; however, these findings are exploratory and cannot be interpreted as direct evidence of altered alertness. Although some within-group effects were observed in the mastic gum group, between-group comparisons did not consistently reach statistical significance. Therefore, the present data do not support definitive conclusions regarding the superiority of mastic gum over regular gum. Rather, the results suggest potential differences that warrant investigation in adequately powered crossover studies.Although these results should be interpreted cautiously, potential mechanisms underlying the observed patterns merit further investigation. Differences in chewing resistance between the two gum types may have contributed to the observed patterns. The regular chewing gum was selected for its relatively higher resistance compared with other commercial gums, although it did not match the resistance of mastic gum. Suzuki *et al*. (29) reported that different consistencies of gum gave different patterns of cerebral blood flow and heart rate changes. Potential effects of bioactive compounds present in natural mastic gum should also be considered. Reported benefits of mastic for oral and general health (5, 30) may be relevant, although their contribution to the present findings cannot be determined.

Accordingly, the present study should be viewed as an initial step toward more rigorous investigations evaluating the potential impact of chewing-related interventions on well-being.

Following correction for multiple comparisons, only a limited number of effects remained statistically significant, consistent with the exploratory nature of this pilot study.

6. Conclusions

This pilot study demonstrates the feasibility of conducting combined subjective, physiological, and wearable heart rate and EEG assessments of chewing-related responses in an adolescent student sample in a school setting. Short-term increases in self-reported alertness were observed during chewing, whereas; while EEG measures did show considerable numerical changes, they exhibited considerable inter-individual variability and sensitivity to experimental conditions, underscoring their exploratory nature in this context.

Although no consistent between-group differences were detected between regular and natural mastic gum, the study provides valuable information on measurement variability, practical constraints, and methodological challenges inherent to studying acute neurophysiological responses to chewing in adolescents. In particular, the findings highlight the importance of controlling for chewing-related muscle artifacts, standardizing recording durations, incorporating appropriate control conditions, and adopting crossover designs in future work. Overall, the present results should be interpreted as hypothesis-generating rather than confirmatory. The study contributes by informing the design of future adequately powered, controlled, and blinded investigations aimed at evaluating the cognitive and neurophysiological effects of chewing gum under more rigorous experimental conditions.

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Appendix 1. Visual Analog Scale (VAS)

How alert do you feel?
Very little_____Very much

How sad do you feel?
Very little_____Very much

How tense do you feel?
Very little_____Very much

How much of an effort is to do anything?
Very little_____Very much

How happy do you feel?
Very little_____Very much

How weary do you feel?
Very little_____Very much

How calm do you feel?
Very little_____Very much

How sleepy do you feel?
Very little_____Very much