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Drivers' Attitude Towards Caffeine Chewing Gum As Countermeasure To Driver Task-Related Fatigue

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Abstract

Driver fatigue is one of the major contributors to road accidents. In this study, we refer to task-related fatigue, in contrast to sleep-related fatigue. Sleep-related fatigue decrements in driving performance are related to the circadian rhythm, sleep disorders, and sleep deprivation or restriction. Task-related fatigue depends on driving conditions: active and passive task-related fatigue may arise according to the combination of driving task and driving environment. Active task-related fatigue is related to overload driving conditions, and passive task-related fatigue with underload ones. Several countermeasures have been proposed to face the problem of driver fatigue, such as taking a nap or caffeine beverages. The intake of caffeine has shown the enhancement of vigilance and choice reaction time. Those enhancements have an effect within 5-10 min in a caffeine chewing gum compared with 30 to 45 min in coffee. The enhancement in alertness within 5 min is crucial and potentially can reduce sleep related car accidents. Recent study showed that the caffeine effect is directly related to driving performance in monotonous conditions. In this study, two groups of drivers were asked to provide their preferences on several products that might positively affect their driving performance on long and monotonous conditions. The first group composed of participants that drove a driving simulator and actually consumed the products. The second group was composed of questionnaire responders that were presented with animations replicating the first group's actual driving. Both groups' participants preferred to consume coffee or regular chewing-gum over caffeine chewing gum when asked at the beginning of the experiment (or survey). Drivers that actually consumed the products changed their attitude in favour of caffeine chewing-gum. On the other hand, the drivers that participated in the survey did not change their attitude, but rather changed their attitude with regards to the safety in using caffeine chewing-gum.

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1. Introduction

Driver fatigue is one of the major contributors to road accidents (MacLean, Davies et al. 2003). Fatigue is an internal situational factor associated with road safety behavior and, as the result of research, is today known to be a dominant factor in road accidents (Sagberg 1999).

The term "fatigue" includes physical and mental sensations that encourage the individual to moderate his or her physical and mental actions. There is no specific acceptable definition of fatigue in the context of road accidents in the relevant literature. Usually fatigue is defined by subjective terms such as a feeling of tiredness or by an objective measurement of reaction time (Dinges and Kribbs 1991, Dinges 1992, Dinges 1995). Fatigue is one of the most significant causative factors in road accidents and a tendency to fall asleep at the wheel is a deciding factor in one fifth of road accidents that occur (Shteer, Vinker et al. 2003). Research findings indicate that fatigue has a detrimental effect on driving even when the driver does not fall asleep at the wheel (Dinges 1995, Gillberg and Åkerstedt 1998) and that cognitive and psychomotor function decreases as manifested by distraction, loss of concentration, poor judgment, slowed reactions and performance errors. Additionally, findings showed that over-fatigued individuals have a 2.7 greater risk of being involved in road accidents(Weissberg, Oxenberg et al. 2007).

As mentioned previously, in recent years, numerous studies have been carried out on the many effects of fatigue on driving, the results of driving while fatigued (McConnell, Bretz et al. 2003) and risk perception when driving in a fatigued state (Lucidi, Russo et al. 2006).

The analysis presented here is based on the study by May and Baldwin (2009), who proposed a sub-categorization for fatigue based on its causal factors, making a distinction between sleep-related and task-related fatigue. Sleep-related fatigue decrements in driving performance are related to the circadian rhythm, sleep disorders, and sleep deprivation or restriction. Task-related fatigue depends on driving conditions: active and passive task-related fatigue may arise according to the combination of driving task and driving environment. Active task-related fatigue is related to overload driving conditions, and passive task-related fatigue with underload ones.

According to this sub-categorization of fatigue, this paper examines the passive task-related effect of prolonged driving in a monotonous highway environment. Safe handling of a vehicle requires sustained attention, but monotony leads to the opposite (Thiffault and Bergeron 2003, Ting, Hwang et al. 2008). This factor, in particular, plays a fundamental role in the onset of passive task-related fatigue: situations of mental underload and monotonous driving may mean that the driving task becomes automated (Desmond, Hancock et al. 1998). The time of day effects also gradually impairs driving performance and leads to an increase in accident risk (Connor, Norton et al. 2001).

Several countermeasures have been proposed to face the problem of driver fatigue (Dinges, Maislin et al. 2005), such as taking a nap (Philip, Taillard et al. 2006) or caffeine beverages (Mets, Ketzer et al. 2011, Mets, Baas et al. 2012). The intake of caffeine has showed the enhancement of vigilance and choice reaction time (Lieberman, Tharion et al. 2002, McLellan, Kamimori et al. 2005). As the onset of action of the caffeine is reliant on the speed of delivery, a faster absorption results in a shorter duration for an active response. The absorption of caffeine in a liquid or capsules is mainly via the intestinal and hepatic first pass. However, the caffeine in a chewing gum is absorbed via the mouth tissues, which results in bypassing the intestinal and hepatic first pass metabolism. This bypass consequence in onset of action of the caffeine within 5-10 min in a caffeine chewing gum compared with 30 to 45 min in capsules (Kamimori, Karyekar et al. 2002). The enhancement in alertness within 5 min is crucial and potentially can reduce sleep related car accidents.

Several studies have also dealt with the effectiveness of caffeinated chewing-gum as a countermeasure to fatigue in airplane pilots or military personnel (Lieberman, Tharion et al. 2002, McLellan, Bell et al. 2004, Bonnet, Balkin et al. 2005, McLellan, Kamimori et al. 2005).

Previous paper by the authors (Gastaldi, Rossi et al. 2016) analyzed driver fatigue behavior and the effectiveness of caffeine chewing-gum as a countermeasure to fatigue. Data collected by a driving simulator in the laboratory were used to measure changes in driving performance. The self-perceived measure of fatigue was also analyzed. The negative effects on driving performance of prolonged driving and the effectiveness of the Standard Deviation of Lateral Position in representing worsening driving performance were demonstrated. Fig. 1 demonstrates that, with the x-axis represents 5 minutes intervals, for which the SDLP (y-axis) was averaged for all participants. Fig. 2 illustrated the difference between the SDLP of the control test and the caffeine chewing-gum test. This analysis indicates that intake of caffeine in the form of caffeine chewing-gum (100 mg caffeine) improves driving performance in less than 10 minutes; drinking an ordinary cup of coffee (with the same caffeine content) does not improve driving performance in the same short time interval (Fig. 3).

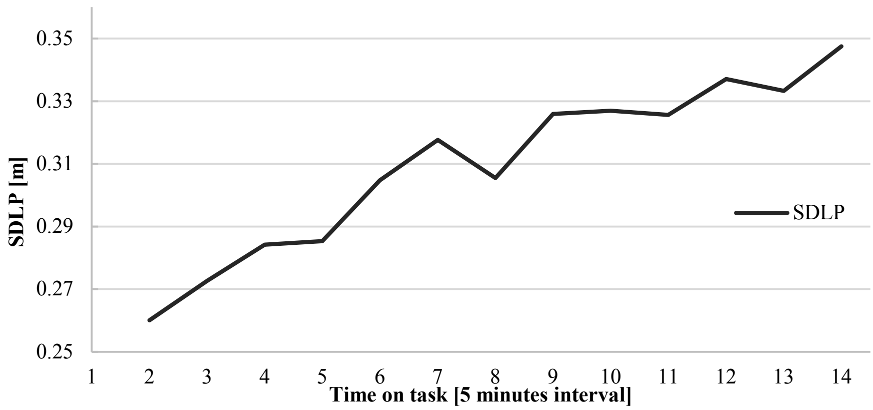

Fig. 1. Standard Deviation of Lateral Position (SDLP): mean values per 5-minute intervals.

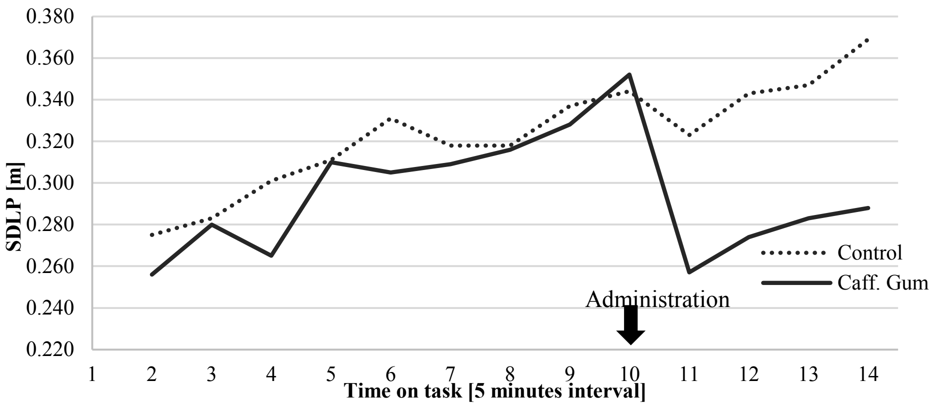

Fig. 2. SDLP: Caffeine Gum vs Control.

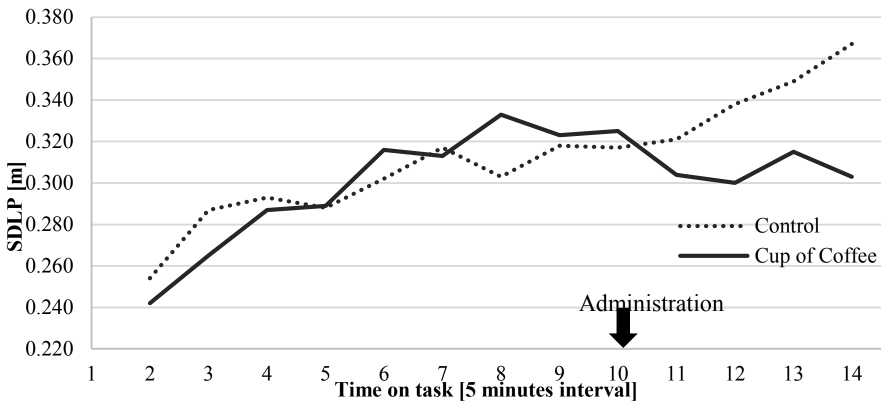

Fig. 3. SDLP) Cup of Coffee vs Control.

1.1. Aim and objectives

The aim of this paper is to assess drivers' willingness to use voluntarily caffeine chewing-gum as a countermeasure to task-related fatigue. Military personnel, whom are bound to military law, are easily instructed to consume caffeine chewing gum in order to increase safe driving. On the other hand, enforcing civil personnel to consume caffeine chewing gum is much more difficult. Thus, analyzing the factors contributing to the willingness to consume caffeine chewing gum is the objective of this paper.

The paper is organized as follows: Section 2 describes the original experiment methodology and data collection, along with the attitude analysis. Due to the limited number of participants, a questionnaire based analysis was used. Section 3 describes the survey methodology, as well as the results. Concluding remarks and future developments of this research are presented in Section 4.

2. Driving simulator based attitude analysis

As part of the study on the effect of coffee and caffeine chewing-gum as a countermeasure to driver task-related fatigue (Gastaldi, Rossi et al. 2016), data was collected in order to assess the participating drivers' perception of the usefulness of coffee and caffeine chewing-gum to reduce task-related fatigue.

2.1. Methodology

The simulation system used was a dynamic simulator produced by STSoftware®, comprising a realistic cockpit, three networked computers, and five high-definition screens. It was also equipped with a Dolby Surround® sound system, the whole producing realistic virtual views of the road and the surrounding environment. According to Weir and Clarke Weir and Clark (1995), the Transport Research Laboratory’s driving simulator at DICEA (University of Padova) can be considered a mid-level simulator.

The sample of drivers was composed of 72 subjects, all volunteers. They were students, staff of the University and other persons with the following characteristics: 1) at least 1 year's driving experience, 2) at least 5,000 km/year average driving distance, 3) absence of sleep disorders (as measured by the Epworth Sleepiness Scale (Johns 1991)).

A highway environment scenario was built in virtual reality with the 3D software of the driving simulator. The scenario was based on a straight road 164 km long, with two driving lanes (width 3.75 m) and a security lane (width 2.5 m). The right and left carriageways were divided by a traffic island 1.80 m wide, as required by Italian law regarding highway design. A speed limit signal was placed every 10 km to remind drivers of the speed limit in force (130 Km/h).

In the main direction, slight traffic conditions (flow rate about 300 vehicles/h/lane) were simulated. Because drivers were told not to overtake other vehicles, no slow vehicles were present in the right-hand lane, but only one leading and one following vehicle were always moving at the same speed as the volunteer. These accompanying vehicles travelled at a fixed distance of 50 m from the subject's car. In order to enhance the natural effect of the scenario, on the other carriageway (in the opposite direction) light traffic conditions (flow rate about 350 vehicles/h/lane) were simulated. In this flow, 10 % of vehicles were HGVs.

In the laboratory, the temperature was controlled between 20° C and 22° C and brightness by a light meter fixed at 4 lx. Participants familiarized with the simulator during training session. During training, subjects performed a ten-minute practice drive and completed a Simulator Sickness Questionnaire (Kennedy, Lane et al. 1993) to ascertain whether they were subject to simulator sickness. They also compiled the Epworth Sleepiness Scale (Johns 1992) to identify excessive daytime sleepiness considered as a sleep disorder. Selected subjects were randomly assigned to one of the treatments.

When they arrived for the experiment, subjects were asked to fill self-reported questionnaires to ascertain whether they had taken any alcohol or caffeine or had smoked cigarettes. When all criteria had been met, the experiment could begin.

The experiment followed the same common structure. Volunteers were instructed to drive for 70 minutes in the center of the right-hand lane, as they would normally do in the real world, at a speed of about 130 km/h. They were also told not to overtake any vehicles in front of them, but simply to drive along the highway. The volunteers underwent two driving tests on two different days: one "with administration": "cup of coffee", "caffeine chewing-gum", or "placebo chewing-gum") and another as a baseline control test ("without administration").

The two trials were divided into four or five parts, depending on type (with or without administration):

1. Individual interviews of participants, to collect information about their state of fatigue.
2. 50 minutes' driving.
3. Administration of treatment.
4. 20 minutes' driving.
5. Individual interviews to collect information about participants' state of fatigue and the driving task at the end of the trial and during it.

The scenario was always the same: a monotonous environment with pairs of trees regularly placed on both sides of the road and façades of trees closing the line of vision on the horizon.

In order to avoid any effects due to circadian rhythm, test sessions were scheduled at the same time in the afternoon and early evening (15:30-19:00), outside the “post-lunch dip” for each trial (Zhang, Yan et al. 2014). Cups of coffee (110mL) was made with Nespresso Roma capsules containing about 100 mg of caffeine (Carvalho, Weller et al. 2010, Damm and Kappe 2011). The caffeinated chewing-gum contained 100 mg of caffeine.

As part of the experiment (Gastaldi, Rossi et al. 2016), each of the 72 participants was asked to complete questionnaires: before, and after driving. In the first questionnaire (before driving), each participant stated: 1) which product is preferred to consume while driving (caffeine chewing-gum, coffee, and chewing gum), and 2) if there is a difference between the products. In the second questionnaire (after driving), each participant asked to state which product is preferred during driving. If caffeine chewing-gum or chewing-gum were administered during driving (48 participants), he or she was asked to state if caffeine chewing-gum is preferred or nothing at all. If coffee was administered (24 participants), the selection was between coffee and nothing to consume.

2.2. Results

We performed Logit and multinomial logit analysis on the before and after questionnaires. The multinomial logit analysis (Table 1), with the base category as "will not take any product", shows that before driving, the participants have the following preferences: (1) mint chewing gum, (2) Coffee, (3) taking nothing, (4) caffeine chewing gum. As the results are statistically significant, we can state that the participants have negative attitude towards the caffeine chewing gum (especially because they have not consumed any kind of caffeine chewing gum before because this product is not easily available).

The analysis of the second questionnaire revealed that: a) The preference order is changed: (1) caffeine chewing gum, (2) taking nothing, (3) coffee, (4) mint chewing gum. b) Participants who consumed caffeine chewing gum, will be likely to consume the same product in the future. While participants who consumed coffee or mint chewing gum, are less likely to consume the same product (Table 2). It is imperative to understand that the participants were not notified about the effect of the product at the end of the test. This indicates that some participants subjectively found that caffeine chewing gum improved their driving performance.

Table 1. Multinomial Logit Estimate before and after driving.

	Before driving		After driving	
	Coefficient	Std. Err.	Coefficient	Std. Err.
Caffeine chewing gum	-0.86*	0.42	0.61	0.33
Coffee	0.79**	0.28	-1.94**	0.75
Mint chewing gum	1.06**	0.27	-2.63**	1.03

*- significance level of 0.05
**- significance level of 0.01

Table 2. Logit estimate after driving.

		Consumed			
Will consumed		Caffeine gum	Mint chewing gum	Coffee	Any Gum
Caffeine gum	Coefficient	1.16*	-0.18		0.42
	Std. Err.	0.51	0.42		0.31
Coffee	Coefficient			0.91	
	Std. Err.			0.48	

*- significance level of 0.05

3. Survey-based attitude analysis

Section 2 presented the attitude analysis of drivers that 1) experienced near-real driving conditions (with the driving simulator) and 2) consumed coffee and caffeine chewing-gum. As a complementary analysis, a survey based analysis was performed. The aim of this analysis is twofold, and directly correlated to the current study's objectives: 1) to increase the number of observations for the statistical analysis, and 2) to investigate the attitude of potential drivers, that did not experience the effect of coffee or caffeine chewing-gum. The first objective stems from the fact that the original experiment is time consuming (total of around three hours per participant) and participants' recruitment is complex. On the other hand, on-line surveys are much easier to perform. The second objective is related to the fact that we are interested with any driver's perception towards caffeine chewing-gum, not only those that experienced the product.

The major challenge at hand is the construction of a survey that will be both short and easy to understand, while resembling the driving simulator experiment.

3.1. Methodology

The online survey has similar questionnaires to the driving simulator experiment, with the driving part being substituted by video clips animating the steering-wheel movements while driving, illustrated in Fig. 4. The animation visually replicates the SDLP measure, as frequent and wider oscillation of the black dot correlate to higher SDLP. Actual steering-wheel data were extracted from the driving simulation experiments' logs, and randomly selected to represent different driving profiles. Based on the SLDP curve, the driver's types were defined as: 1) average, 2) fatigue prone, and 3) fatigue resistant. Each type was identified based on the specific driver SDLP curve with relation to the average SLDP curve. Hence, type #1 driver has a curve close to the average SLDP, while drivers' types #2 and #3 have steeper and less steep curves than the average SDLP curve, respectively. Furthermore, for each driver type, four animations were created representing the four tests (control, coffee, caffeine chewing-gum, placebo chewing-gum). Because an on-line survey cannot practically take more than several minutes, a one-minute video clip was prepared for each of the 12 animations. Each clip was constructed from the following parts: 1) a message informing that the test drive is starting, 2) 30 seconds representing the first 8 minutes of driving with x16 speed, 3) a message informing that 53 minutes elapsed, 4) a message informing that coffee or chewing-gum was administered (for coffee/gum/placebo tests), 5) 30 seconds representing the 8 minutes after administration, with x16 speed, and 6) a message informing that the test is over.

Those animations were integrated within the general structure of the survey:

1) General description of the survey: information presented to the participant with regards to the aim of the survey, similar to the one described to the driving simulator participants.
2) Personal related questions, such as age, gender, and education.
3) Transportation related questions, such as driving license type, driving experience, annual mileage, car ownership, driving violation and accidents history.
4) Pre-test attitude assessment: driver's attitude to coffee, caffeine chewing gum, and regular chewing gum.
5) Description of the driving simulator test, with a short video demonstrating the driving simulator cockpit and environment.
6) Three animations representing the control, coffee, and chewing gum drives, as described at the beginning of the section. Three randomization were generated. a) driver type selection (#1, #2, and #3), b) caffeine chewing gum of placebo administration, c) animations order. After each animation, the participant was asked to rate the willingness to use the product administered.
7) Post-test attitude assessment: driver's attitude to coffee, caffeine chewing gum, and regular chewing gum, after providing additional information with regards to the results of the original study ((Gastaldi, Rossi et al. 2016)). a) The negative effects on driving performance of prolonged driving b) intake of caffeine in the form of caffeinated chewing-gum improves driving performance in less than 10 minutes, c) drinking an ordinary cup of coffee (with the same caffeine content) does not improve driving performance in the same short time interval, d) regular chewing gum has no positive effect on driving performance.

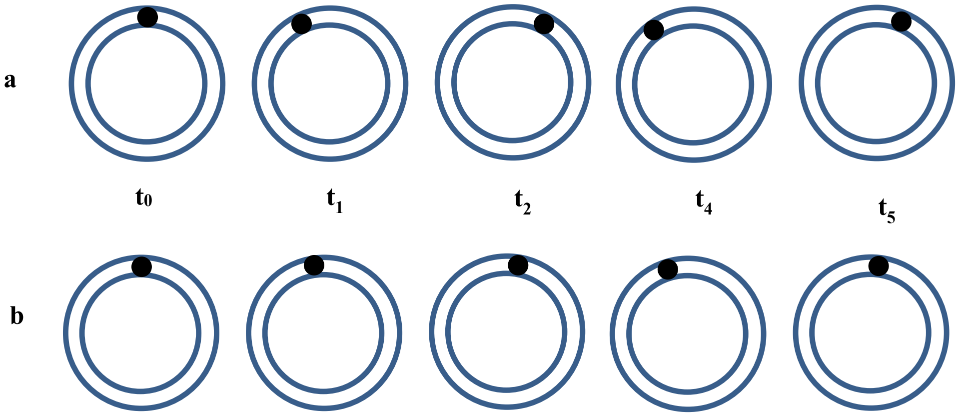

Fig. 4. Animation of SDLP as steering wheel movement: (a) – high SDLP, (b) – low SDLP.

3.2. Results

A total of 67 responses were collected (46 male, 21 female). Based on multinomial logit regression the following significant results were observed, as summarized in Table 3.

Several observations are evident. 1) Male and female have different preferences, both before and after the survey. This suggests different marketing or advertisement approach in order to shift the drivers toward caffeine chewing-gum consumption during a long drive. 2) The general attitude toward consuming caffeine chewing-gum was negative, this is probably because the caffeine chewing-gum is not a known product (unlike coffee), and the animations were not effective as driving. 3) On the other hand, the majority of participants changed their attitude with regards to the safest product to consume while driving.

4. Conclusions

In this study, two groups of drivers were asked to provide their preferences on several products that might positively affect their driving performance on long and monotonous conditions. The first group composed of participants that drove a driving simulator and actually consumed the products. The second group was composed of questionnaire responders that were presented with animations replicating the first group's actual driving.

Both groups' participants preferred to consume coffee or regular chewing-gum over caffeine chewing gum when asked at the beginning of the experiment (or survey). Drivers that actually consumed the products changed their attitude in favour of caffeine chewing-gum. On the other hand, the drivers that participated in the survey did not change their attitude, but rather changed their attitude with regards to the safety in using caffeine chewing-gum. This indicated that advertising the advantages of caffeine chewing-gum should be based on actual experience, as well as a different approach for men and women.

Finally, the on-line survey could be enhanced with animations that better convey the effect of the product on the driver. Also, further spreading the survey to specific drivers' groups, such as freight and public transport and analysing other attributed influencing the attitude towards caffeine chewing-gum. The proposed approach can be valuable for designing a real-world experiment, in terms of drivers' selection, routes characteristics, etc..

Table 3. Results of the attitude analysis

Stage	All participants		Male		Female	
at the start of the survey	**Dislike caffeine chewing-gum**		**Prefer coffee over chewing-gum**		**Prefer coffee or chewing-gum**	
	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
caffeine chewing-gum vs coffee as the baseline	-2.80**	0.728	-2.56**	0.733	N/A	N/A
Mint chewing-gum vs coffee as the baseline	-0.031	0.248	-0.368	0.306	0.693	0.462
			Safest product is coffee or chewing-gum		**Safest product is chewing-gum**	
	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
caffeine chewing-gum vs mint chewing-gum as the baseline			-0.118	0.343	-2.01**	0.752
coffee vs Mint chewing-gum as the baseline			-0.405	0.372	-1.32*	0.562
After the caffeine chewing-gum animation	**Will not consume caffeine chewing-gum if sponsored by the employer**		**Prefer chewing-gum**		**Does not prefer chewing-gum**	
	Mean diff	Std. Err.	Mean diff	Std. Err.	Mean diff	Std. Err.
Saw caffeine chewing-gum vs mint chewing-gum	-0.020	0.124	1.043*	0.531	-1.932**	0.842
After the coffee animation	**Will consume coffee if sponsored by the employer**		**Prefer coffee**		**Prefer coffee**	
After disclosing the study results			**Prefer coffee or chewing-gum over caffeine chewing-gum** **Safest product is caffeine chewing-gum**		**Have no preferences** **Safest product is caffeine chewing-gum**	
	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
caffeine chewing-gum vs coffee as the baseline	-0.11	0.27	-0.318	0.328	0.356	0.492
Mint chewing-gum vs coffee as the baseline	-0.88*	0.343	-1.01*	0.412	-0.559	0.626

*- significance level of 0.05
**- significance level of 0.01

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