https://doi.org/10.17221/4/2024-RAE

The effect of stimulants on the responsiveness and biorhythms of young operators of agricultural machinery

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Citation: Hart J., Hartová V. (2024): The effect of stimulants on the responsiveness and biorhythms of young operators of agricultural machinery. Res. Agr. Eng., 70: 143–154.

Abstract: Fatigue behind the wheel has been addressed repeatedly for at least 15 years. Various research projects, studies, and systems have been developed to prove the effect of fatigue on the number of accidents and possibly to inform drivers that this situation has occurred. The article examines the influence of stimulants on the fatigue of young agricultural machinery drivers. Commonly available means for reducing driver fatigue were chosen as stimulants (coffee, tea, maté, guarana, energy drink, lemon extract with sugar). A special test station with automatic reaction time evaluation was developed to test drivers' reaction ability (responsiveness). Furthermore, the effects on the physical condition of the tested persons (systolic blood pressure, diastolic blood pressure, blood pressure amplitude and heart rate) were investigated. The conducted experiments confirmed a statistically significant effect of all tested stimulants, except for tea, for which no statistically significant changes in the monitored parameters were observed.

Keywords: blood pressure; influences; fatigue; physical condition

Fatigue behind the wheel has been addressed repeatedly for at least 15 years. Various research projects, studies, and systems have been developed to prove the effect of fatigue on the number of accidents and possibly to inform drivers that this situation has occurred (Besip 2017). The National Highway Traffic Safety Administration has defined the three most serious variables most likely to cause fatal crashes. These are drunk driving, distracted driving, and fatigued driving (NHTSA 2017, 2018, 2019).

Considering that accident statistics are still not improving much, the European Commission has decided that this factor should be addressed from 2022 onwards by tightening the requirements for standard vehicle equipment to include more safety features. Fatigue (alertness, drowsiness, etc.) monitoring systems will thus become an integral part of vehicles in the future. Although this is new in terms of mandatory equipment, similar systems have been on the market for some time (Smith 2011; Mercedes-Benz 2015; Sajdl 2015; Volkswagen 2015; Anderson 2017; Wagenknecht 2017).

Regular sleep is a simple and convenient defence against fatigue, which should last at least 7–8 h (sometimes up to 9 h is recommended) (Chen et al. 2016; Lee and Jeong 2016; Sparrow et al. 2016; Mahajan et al. 2019). Unfortunately, the use of stimulants to keep drivers awake during states of emerging

Supported by the Czech University of Life Science Prague, (Grant No.: CZU2021:31150/1312/3103) – Air quality in the vehicle cabin in common operation and its active influence to eliminate safety risks.

https://doi.org/10.17221/4/2024-RAE

fatigue is much more common and very dangerous. Drivers often use them in an attempt to influence their fatigue behind the wheel. This leads, for example, to problems with detecting fatigue conditions in the vehicle by fatigue detection systems (Sparrow et al. 2019).

The use of various types of stimulants has become common today. In the beginning, they are usually used when a person starts to feel increased fatigue. Later, when the organism is partially dependent on the stimulant (coffee, tea, energy drink, etc.), users start to apply it even when they are not fatigued. The most common legal stimulant used in this situation is caffeine. It is known to act mainly on the central nervous system (CNS). It is effective in increasing concentration and alertness as well as reducing the resulting fatigue. It occurs naturally in more than 60 plants (*Cola acuminate*, *Theobroma cacao*, *Ilex paraguariensis*, *Paullinia cupana*, *Camelia siniensis*, *Coffea arabica*, *Coffea robusta* etc.) (Sparrow et al. 2019). It is usually consumed in the form of beverages, ranging from coffee to energy drinks. It has been shown to be frequently used by occupational drivers, although it has a relatively short effect on the body (Sparrow et al. 2016, 2019; Owenset al. 2019). However, concerning the effectiveness of caffeine on fatigue it has been shown that gradual repeated dosing of caffeine (200 mg tested) can radically reduce fatigue behind the wheel, eliminating errors arising from drowsy driving (Heckman et al. 2010).

Caffeine administration for fatigue has also been shown to improve reaction times, physical performance, and cognitive function (Aidman et al. 2018; Duncan et al. 2019; Franco-Alvarenga et al. 2019; Souissi et al. 2019; Torres and Kim 2019). The extent of the ergogenic response to caffeine ingestion can vary between individuals, even when the same amount is ingested at the same time. However, a positive change in the body's response to a dose of caffeine has been demonstrated in all individuals (Del Coso et al. 2019).

As with other stimulants, an addiction can develop in case of long-term use. This results in a change in blood flow velocity in the brain, leading to headaches, drowsiness, reduced alertness, etc. (Jones et al. 2000; Juliano et al. 2012).

Until now, the effects of stimulants have only been tested on subjects who "needed" the stimulant. The question, therefore, arose as to how stimulants affect subjects who are not fatigued and only apply the stimulant out of habit or for its taste. The impact of stimulant application can also have a negative effect on the individual's body, as reported by (Higbee et al. 2020). During testing, energy drink consumption was found to impair sleep quality and duration (fewer hours of sleep), and users experienced higher levels of perceived stress. Therefore, emphasis was placed on determining whether stimulant administration had an effect on the test subjects' responsiveness and whether stimulant administration in test subjects 50 min after administration had an effect on systolic blood pressure, diastolic blood pressure, blood pressure amplitude, and heart rate.

What happens to the human body when it is dosed with a stimulant without needing it is very important. Therefore, the main objective of this work is to demonstrate the effect of stimulants on the responsiveness, systolic blood pressure, diastolic blood pressure, blood pressure amplitude, and heart rate of the test subjects.

There are many stimuli that lead to so-called seasonal fatigue, and the only solid link is the fact that it is fatigue that occurs only during a certain period of the season. Seasonal fatigue is very widespread in the general population, and it is allergic fatigue. Allergy sufferers may experience a situation where, if they are exposed to an allergen, they may experience fatigue, reduced attention, mood deterioration, or the onset of dysphoria (anxiety, irritability, subjectively felt discomfort). Another may be, for example, a variant of fatigue caused by an affective disorder (mood disorder), which may also have a seasonal character. (Marshall et al. 2002). If it is seasonal fatigue in the ordinary sense of the word, it is usually fatigue arising from seasonal work, such as running ski resorts, holiday resorts, etc. An example of seasonal work, where there is also great fatigue from overstrain, is the work of an elite fire crew, "interagency hotshot crew", which solves fires across the entire United States. (Baars et al. 2008) But if we were to focus on the work most common for the emergence of seasonal fatigue states, then it would be work in agriculture. (Irwin et al. 2019)

Many studies have already been carried out in the field of fatigue when operating agricultural machinery. The styles of dealing with fatigue and increasing safety were addressed from different angles, opening up many variant solutions to defend against seasonal fatigue effectively. The problem remains that when interviewing the operators of agricultural machinery, it was found that they work "overtime" and often at night. He states that these conditions lead to fa-

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tigue for them. Despite this finding, however, they continue with the given tasks (even though they are tired) because task and financial pressures are exerted on them. (Irwin et al. 2019)

MATERIAL AND METHODS

Since the individual substances were administered to and tested on well-rested subjects, the hypotheses were constructed as follows:

$H1_0$: Stimulant administration does not affect the responsiveness in test subjects 50 min after administration.

$H2_0$: Stimulant administration does not affect systolic blood pressure in test subjects 50 min after administration.

$H3_0$: Stimulant administration does not affect diastolic blood pressure in test subjects 50 min after administration.

$H4_0$: Stimulant administration does not affect blood pressure amplitude in test subjects 50 min after administration.

$H5_0$: Stimulant administration does not affect heart rate in test subjects 50 min after administration.

All tests were performed under laboratory conditions and on healthy, well-rested (at least 5 consecutive nights of regular 8–9 h sleep) subjects aged 22 to 35 years. The methodological procedure was always strictly followed during tests and each subject was always exposed to the same conditions. Since the tests investigated changes in the subjects responses, mornings were chosen for the tests as there was no expectation of different fatigue states of the individual subjects. The tests were carried out under the conditions shown in Table 1, which were monitored at all times and for all tests by a Netatmo weather station.

Instrumentation and measurement equipment were also used to achieve the stated objectives (Table 2).

The reference values were always measured before testing the change in responsive-ness upon stimulant administration and again after completing the tests 50 min after stimulant administration.

Twenty-one subjects were selected for the stimulant testing: 6 females and 15 males. All subjects are habitual caffeine consumers (usually 2 ± 1 cups of coffee daily). All measurements were performed in 10 cycles. Measurements were performed as follows:

•Verification of laboratory conditions.

•Bringing the subject to the measuring station (Figure 1).

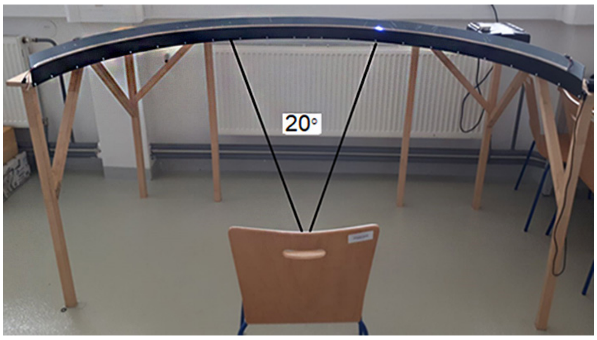

Figure 1. The measuring station

Table 1. Test conditions

Conditions	Range
Temperature	22 to 25 °C
Relative humidity	50 to 70%
Atmospheric pressure	90 to 100 kPa
CO_2 concentration	400 to 800 ppm

Table 2. Instrumentation and measurement equipmen

Instrumentation or equipment name	Equipment function	Type of equipment (accuracy)
Weather station	Control measurements of laboratory conditions (temperature, humidity, pressure, CO2).	Netatmo Indoor (± 0.3 °C, ± 3%, ± 1 mbar, ± 50 ppm)
Pulse oximeter	Measurement by a non-invasive optical method with outputs: heart rate (PRbpm). CE certification as a medical device.	iHealth PO3 (± 2 bpm)
Pressure gauge	For measuring systolic and diastolic blood pressure and blood pressure amplitude.	Hartmann Veroval (± 3 mmHg)
Measuring station for responsiveness detection	It consists of a structure, programmable LED strip, power supply, switch, and development platform ESP8266 ESP-12E OTA WeMos D1 CH340 WiFi Arduino IDE UNO R3	self-made instrumentation

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·Instructing the subject on the control of the measuring station.

·The subjects had to watch the blue diode carefully (this is a distraction process). If a purple LED appeared, they had to press the button they were holding as quickly as possible. To restart the test cycle, they had to hold the button for > 1 s afterwards.

·A 5-minute break to reach a steady state.

·Measurement of a reference sample of heart rate, systolic and diastolic blood pressure and blood pressure amplitude *via* a Veroval blood pressure monitor (HARTMANN, Germany) and an iHealth PO3 pulse oximeter (iHealth, USA).

·Measurement of a reference sample of responsiveness. The measuring station was set up in the following way: The blue LED on the LED strip was within ± 10° of the centre of the LED strip at the measuring station. The head position, this field was thus 20°, due to the fact that the range of the central field of view of a healthy individual is 30° (A possible slight turn of the head was anticipated). Each time the test was run, a purple initialisation LED appeared at a random interval of 5–10 s (Figure 2). It appeared at a distance of ≥ ± 5 diodes from the blue LED in the defined area where the blue LED was moving.

·Then the stimulant was administered. The following products were chosen as common stimulants (the manufacturer's recommended dosage was used):

Coffee – brazil mogiana, 9 g of ground coffee per dose, 2 dL per dose.

Tea – china gunpowder, 5 g of loose tea per dose, 2 dL per dose.

Maté – maté rancho (*Ilex paraguariensis*), 5 g of loose maté per dose, 2 dL per dose.

Guarana – an alcohol-free tincture made of the fruit of the *Paullinia cupana* plant; 20 drops (equivalent to 925 mg of fresh fruit).

Energy drink – the original Monster energy drink 0,5 L, [ingredients: water, sucrose, glucose syrup, acid (citric acid), aroma, carbon dioxide, taurine (0.4%), acidity regulator (sodium citrates), ginseng root extract (0.08%), L-carnitine-L-vinate (0.04%), caffeine (0.03%), preservatives (sorbic acid, benzoic acid), colourant (anthocyanins), vitamins (B3, B6, B2, B12), sodium chloride, D-Glucuronolactone, guarana seed extract (0.002%), inositol. nutrition facts per 100 mL: Energy 201 kJ per 47 kcal, Fat 0 g, of which saturates 0 g, carbohydrates 12 g, of which sugars 11 g, protein 0 g, salt 0.19 g, riboflavin 0.7 mg, niacin 8.5 mg, vitamin B6 0.8 g, vitamin B12 2.5 µg.]

Lemon extract with sugar – 0.5 pcs lemon and 3 pcs cube sugar per 0.3 L of water.

·Measurement of the resulting values – since stimulant administration, each subject was measured on each test after 50 min. Everything was done in the same way as during the reference tests.

·Measurement of the final sample heart rate, systolic and diastolic blood pressure, and blood pressure amplitude using a Veroval blood pressure monitor.

The normality of the data was determined using the Shapiro-Wilk test, which is suitable for data in the range ($N \leq 2\,000$). This method was, therefore, chosen to test the normality of the data in subsequent processing. When testing using the Shapiro-Wilk test, the assumption is that the normality of the data exists and the significance level is set at $\alpha = 0.05$.

For further statistical data processing, the significance level was also set at $\alpha = 0.05$. All statistical calculations were performed using the software STATISTICA (version 12.0.1133.15).

Determination of statistical methods. There are 5 independently solved units, which always form two data samples. The independent units are responsiveness, systolic pressure, diastolic pressure, blood pressure amplitude and heart rate. There is two data samples before stimulant application and 50 min after stimulant application.

The data are interdependent. These measurements were performed on the same subjects before and after stimulant application. If one data set turned out to be non-normal (according to the Shapiro-Wilk test), it would not be possible to follow the statistics presuming the normality of the data. Therefore, if this situation arises, both data sets will be considered for subsequent processing as data series without normality. Based on the dependence and normality of the data, the statistical method "The paired samples Wilcoxon test" was chosen for statistical evaluation.

Figure 2. Initiation by the measuring station

https://doi.org/10.17221/4/2024-RAE

RESULTS AND DISCUSSION

After testing the normality of the data (Table 3) according to the Shapiro-Wilk test, it was found that the data did not meet normality and therefore the statistical method of a paired samples Wilcoxon test will be used.

Result of $H1_0$: Stimulant administration has no effect on the responsiveness in test subjects. The measurements results of $H1_0$ are summarized in Table 4. The results listed in Table 4 show that a statistically significant change was obtained after the use of lemon extract, when the reaction time was prolonged. Figure 3F shows that there is a prolongation of about 14 ms (derived from the mean values).

Table 3. Results of the Shapiro-Wilk test

Values tested	W-value	*P*-value
Responsiveness	0.94791	0.00001
Systolic pressure	0.93379	0.00000
Diastolic pressure	0.97847	0.01026
Pressure amplitude	0.96666	0.00046
Heart rate	0.98321	0.04014

Result of $H2_0$: Stimulant administration has no effect on systolic blood pressure in test subjects 50 min after administration. The results in Table 5 show that after the use of guarana, the systolic pressure was decreased. Figure 4D shows that there is a decrease of about 3 mm mercury (Hg) (derived from mean values).

The results show that the energy drink increases systolic pressure. Figure 4E shows that there is an increase of about 13 mm Hg (derived from mean values).

Result of $H3_0$: Stimulant administration has no effect on diastolic blood pressure in test subjects 50 min after administration. The results in Table 6 show that guarana reduces diastolic

Table 4. Statistical evaluation of the effect of stimulants on responsiveness

Coffee	Tea	Maté	Guarana	Energy drink	Lemon extract with sugar
$P > α$	$P > α$	$P > α$	$P > α$	$P > α$	$P < α$
0.826	0.695	0.056	0.602	0.199	0.011
decrease	decrease	decrease	decrease	increase	increase

red values mean a statistically significant difference

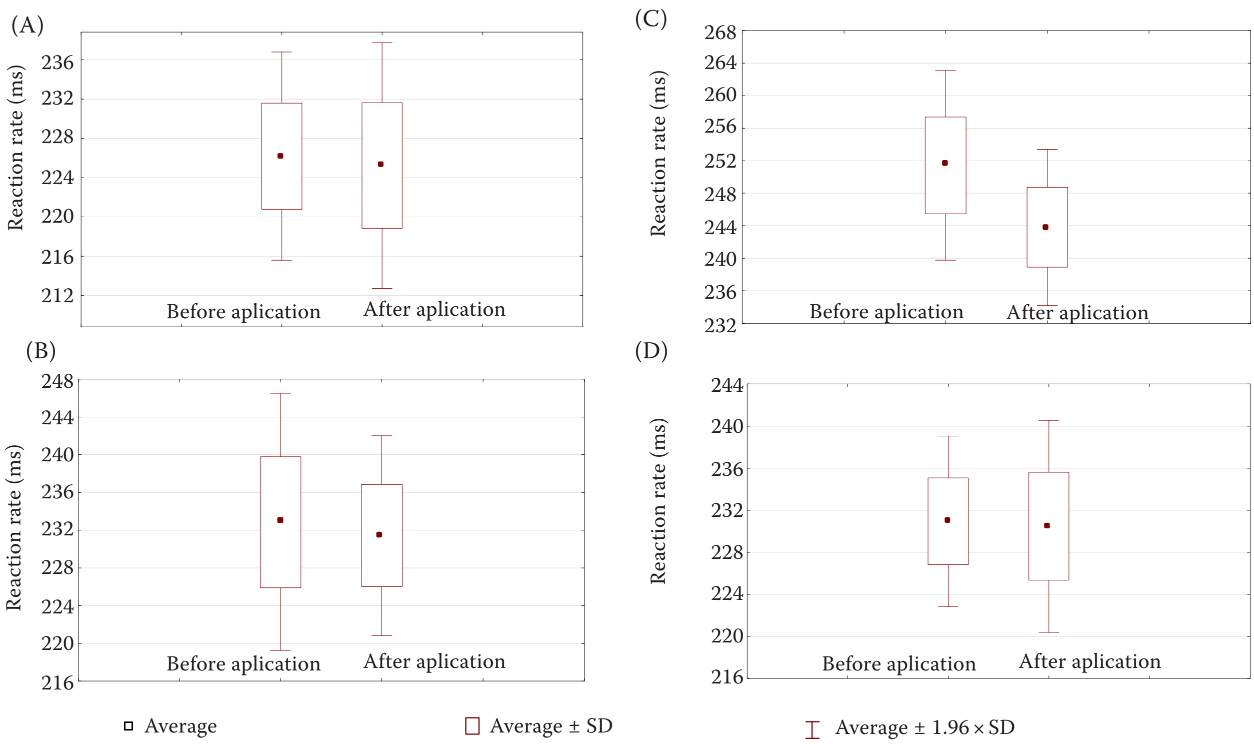

Figure 3. Visual representation of responsiveness results before and after stimulant administration for: (A) coffee, (B) tea, (C) maté, (D) guarana, (E) energy drink, and (F) lemon extract with sugar

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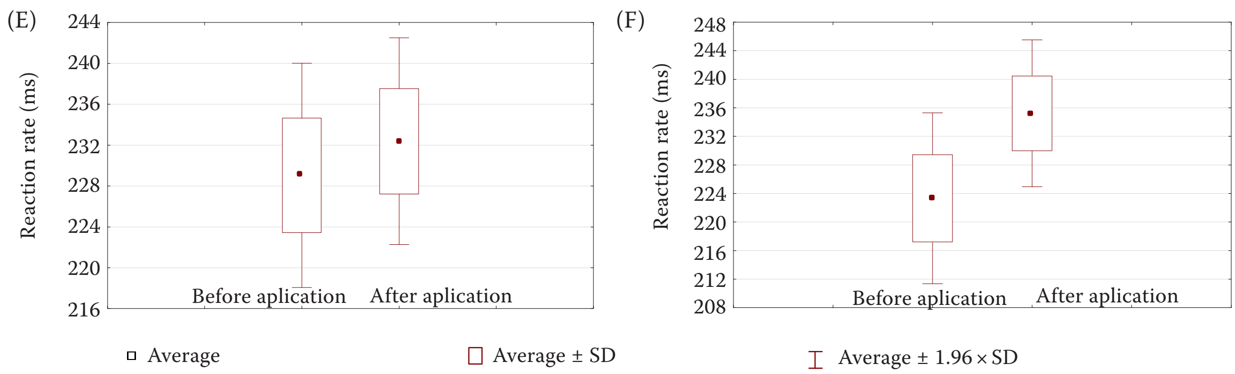

Figure 3. to be continued

Table 5. Statistical evaluation of the effect of the stimulants on systolic blood pressure

Coffee	Tea	Maté	Guarana	Energy drink	Lemon extract with sugar
$P > \alpha$	$P > \alpha$	$P > \alpha$	$P < \alpha$	$P < \alpha$	$P > \alpha$
0.255	0.557	0.339	0.001	0.000	0.058
decrease	decrease	decrease	decrease	increase	decrease

red values mean a statistically significant difference

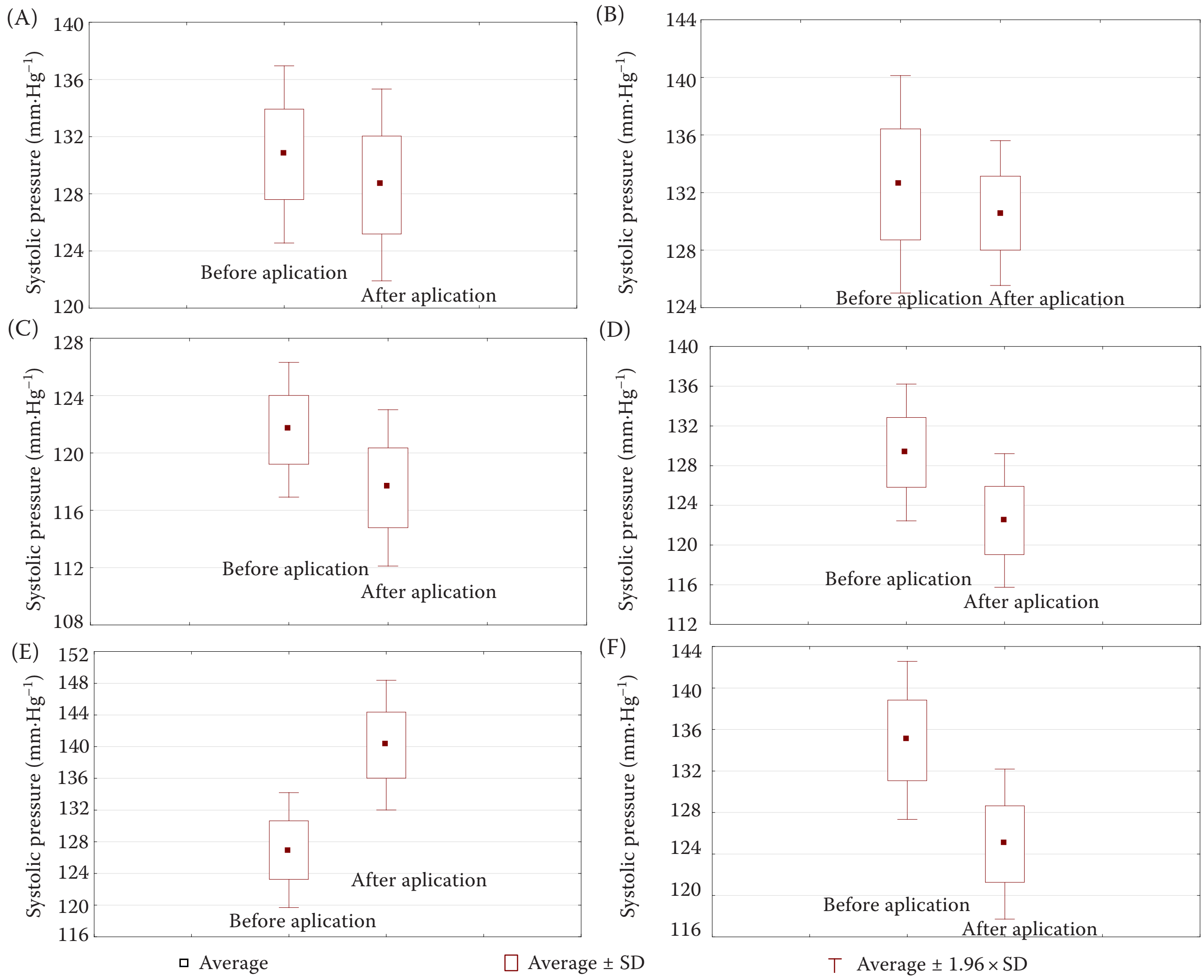

Figure 4. Visual representation of systolic blood pressure before and after stimulant administration for: (A) coffee, (B) tea, (C) maté, (D) guarana, (E) energy drink, and (F) lemon extract with sugar

https://doi.org/10.17221/4/2024-RAE

Table 6. Statistical evaluation of the effect of the stimulants on diastolic blood pressure

Coffee	Tea	Maté	Guarana	Energy drink	Lemon extract with sugar
$P > \alpha$	$P > \alpha$	$P > \alpha$	$P < \alpha$	$P > \alpha$	$P > \alpha$
0.181	0.085	0.543	0.001	0.092	0.064
increase	decrease	decrease	decrease	increase	decrease

red values mean a statistically significant difference

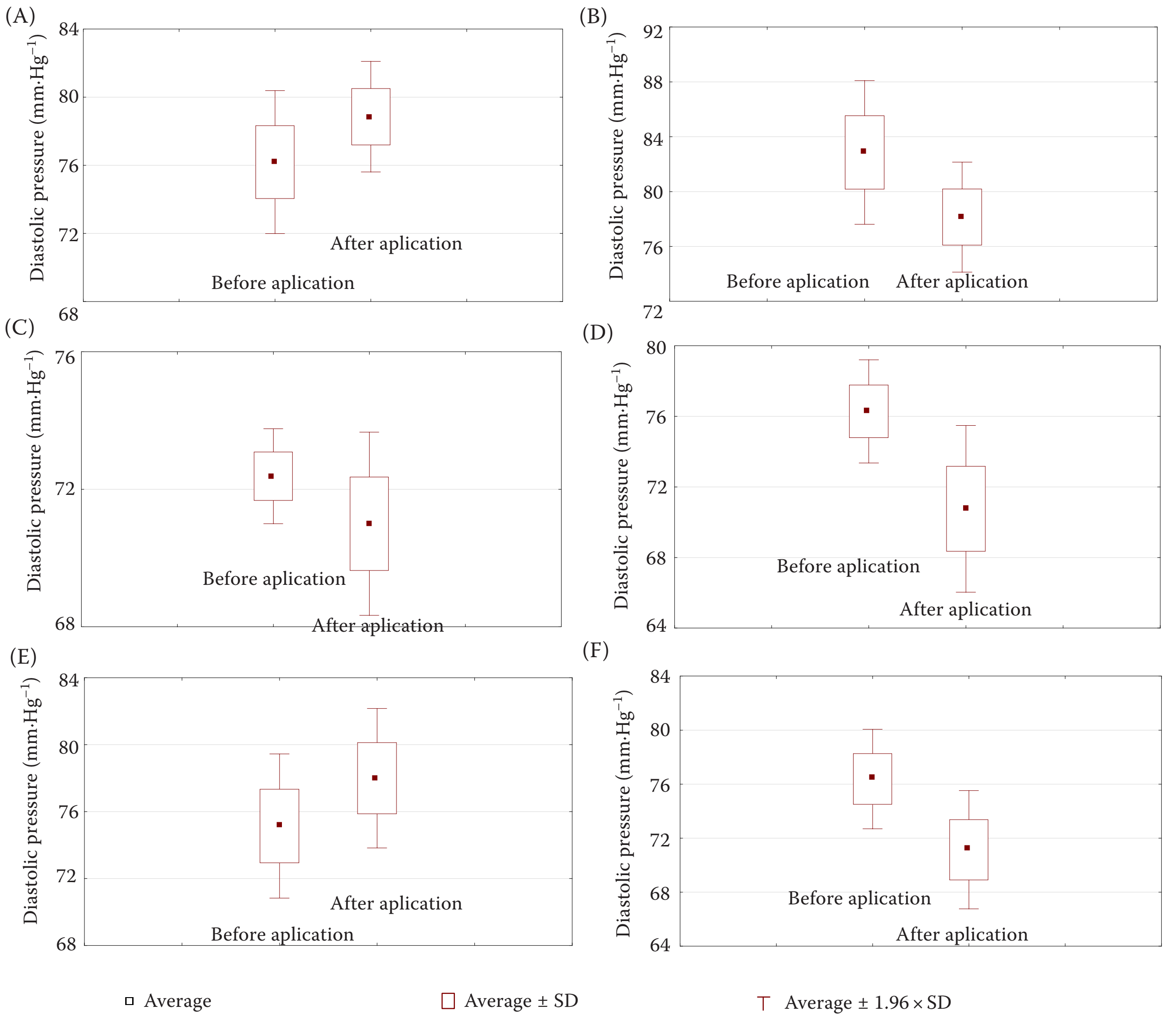

Figure 5. Visual representation of diastolic blood pressure before and after stimulant administration for: (A) coffee, (B) tea, (C) maté, (D) guarana, (E) energy drink, and (F) lemon extract with sugar

pressure. Figure 5D shows that there is a decrease of about 5 mm. Hg (derived from the mean values).

Result of $H4_0$: Stimulant administration has no effect on blood pressure amplitude in test subjects 50 min after administration. The results in Table 7 show a statistically significant effect of coffee, energy drinks and lemon extract on pressure amplitude. Figure 6A show a decrease of about 4 mm. Hg (derived from the mean values) in blood pressure amplitude after drinking coffee. Energy drink (Figure 6E) increases the blood pressure amplitude by about 11 mm. Hg (derived from mean values). Lemon extract with sugar (Figure 6F) reduces the pressure amplitude by about 6 mm. Hg (derived from the mean values).

Result of $H5_0$: Stimulant administration has no effect on heart rate in test subjects 50 min after administration. The results in Table 8 show a statistically significant effect of maté on heart rate

https://doi.org/10.17221/4/2024-RAE

Table 7. Statistical evaluation of the effect of the stimulants on blood pressure amplitude

Coffee	Tea	Maté	Guarana	Energy drink	Lemon extract with sugar
$P < \alpha$	$P > \alpha$	$P > \alpha$	$P > \alpha$	$P < \alpha$	$P < \alpha$
0.022	0.125	0.149	0.394	0.011	0.002
decrease	increase	increase	decrease	increase	decrease

red values mean a statistically significant difference

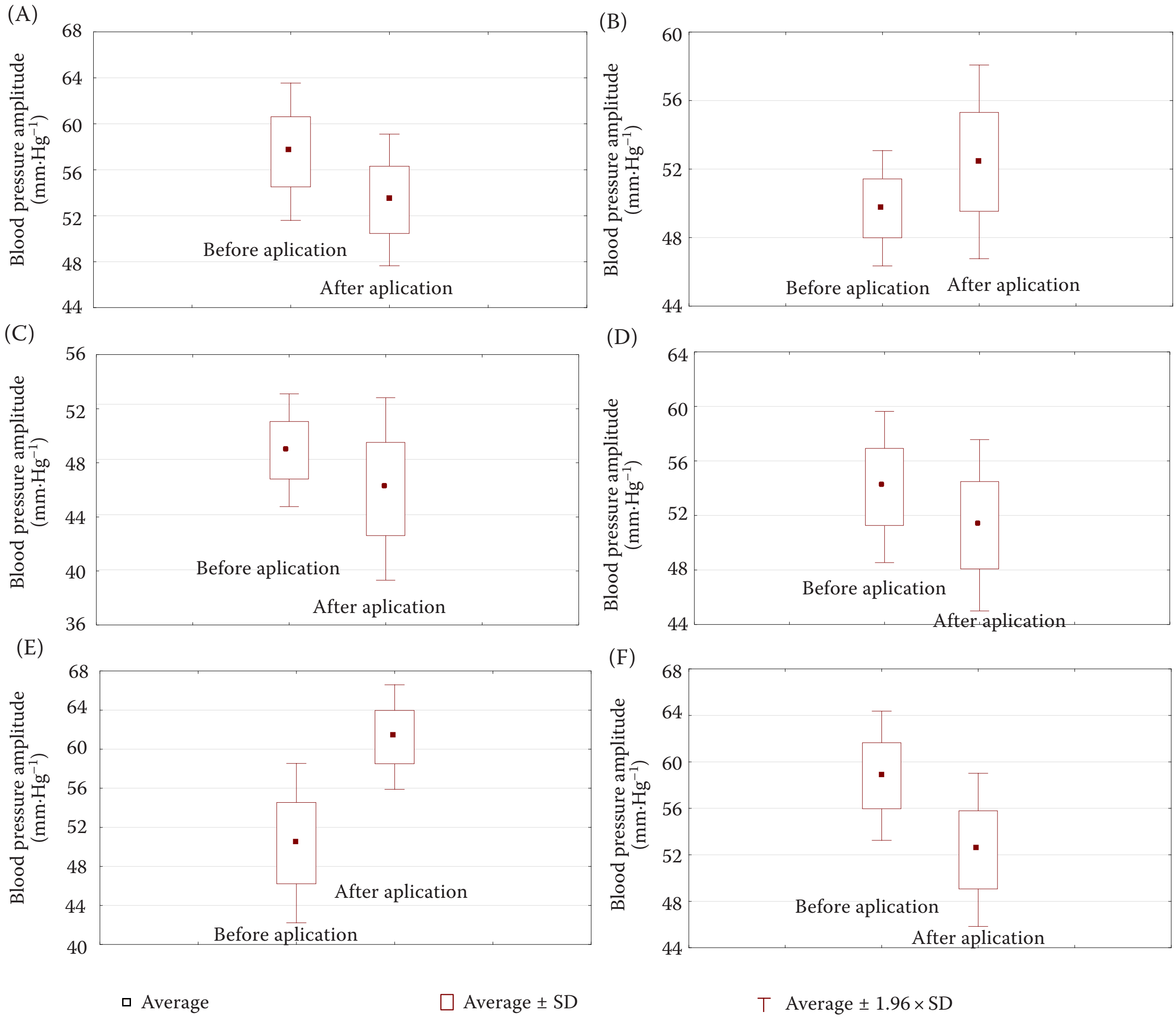

Figure 6. Visual representation of blood pressure amplitude before and after stimulant administration for: (A) coffee, (B) tea, (C) maté, (D) guarana, (E) energy drink, and (F) lemon extract with sugar

increases. There is an increase of about 6 bpm (derived from the average values).

The summary results of the stimulants are presented in Table 9, from which can be seen that all established null hypotheses can be rejected, because at least one stimulant always caused a statistically significant change in the monitored parameter.

Research on the onset of caffeine's effects shows they are not immediate. This is due to the time it takes for caffeine to be absorbed from mucous membranes and individual organs. (Jay et al. 2006) along with (Hindmarch et al. 2000), defined the onset of caffeine between 30 and 60 min after oral ingestion of the stimulant. This time is partially confirmed by (Grgic et al. 2019), who state that caffeine should be administered 60 minutes before the required onset. In contrast, (Heckman et al. 2010) report that approximately 90% of the caffeine contained in the stomach processes

https://doi.org/10.17221/4/2024-RAE

Table 8. Statistical evaluation of the effect of the stimulants on on heart rate

Coffee	Tea	Maté	Guarana	Energy drink	Lemon extract with sugar
$P > \alpha$	$P > \alpha$	$P < \alpha$	$P > \alpha$	$P > \alpha$	$P > \alpha$
0.170	0.876	0.000	0.760	0.835	0.068
decrease	decrease	increase	stagnation	stagnation	decrease

red values mean a statistically significant difference

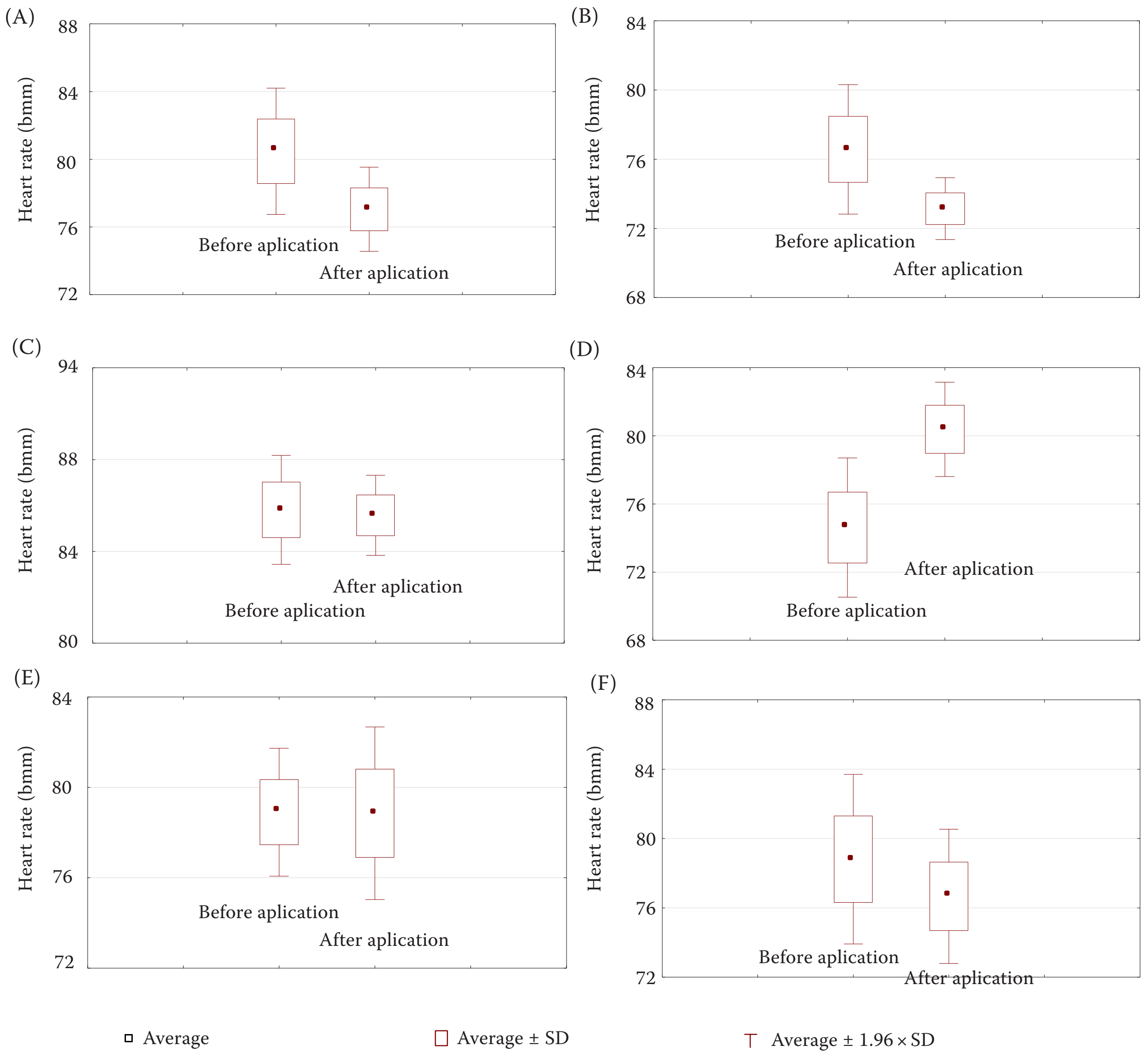

Figure 7. Visual representation of heart rate before and after stimulant administration for: (A) coffee, (B) tea, (C) maté, (D) guarana, (E) energy drink, and (F) lemon extract with sugar

1 cup of coffee within the first 20 min. The maximum plasma concentration is then reached in approximately 40 to 70 min. However, changes in responsiveness have not been statistically demonstrated following the administration of stimulants.

Interestingly, according to the verbal description of the subjects, guarana had the best stimulation results, but they complained about its taste. Regarding the energy drink, some felt an impaired ability to concentrate. They reportedly felt no change for coffee, tea, maté, and lemon with sugar. The measured values do not fully correspond with the sensory perceptions, and therefore a verification measurement of the biorhythms of the test subjects before and after testing

https://doi.org/10.17221/4/2024-RAE

Table 9. Summary of the effect of stimulants 50 min after administration

Parameter	Coffee	Tea	Maté	Guarana	Energy drink	Lemon ex. sugar
Systolic blood pressure	decrease	decrease	decrease	decrease	increase	decrease
Diastolic blood pressure	increase	decrease	decrease	decrease	increase	decrease
Blood pressure amplitude	decrease	increase	increase	decrease	increase	decrease
Heart rate	decrease	decrease	increase	stagnation	stagnation	decrease
Reactiveness	decrease	decrease	decrease	decrease	increase	increase

*statistically significant differences are shown in red

was carried out. From the results, it can therefore be assumed that the test subjects were describing the effect on their biorhythms and subjective comfort rather than on their responsiveness when describing the effect. They perceived the increase in pressure negatively in this situation and, on the contrary, they perceived the decrease in pressure positively.

The findings are consistent with those of (Higbee et al. 2020) who monitored energy drink use among nurses working in a clinical setting. There were significant relationships between energy drink consumption and sleep quality, sleep quantity and perceived stress levels. Nurses who consumed energy drinks had poorer sleep quality and fewer sleep hours than caffeine. Also, nurses who consumed energy drinks had higher levels of perceived stress than those who did not consume caffeine. Due to the fairly unique focus of the tests, the energy drink tests by (Higbee et al. 2020) are the only ones that partially confirm the measured results.

Most of the substances tested in this study (coffee, tea, maté, guarana and energy drinks) contain caffeine. Caffeine was selected since it is the most frequently used stimulant. Caffeine mainly acts on the CNS (central nervous system). It is effective in increasing concentration and alertness as well as reducing the resulting fatigue. It is found in nature in more than 60 plants, e.g: (Heckman et al. 2010): cola nut (*Cola acuminate*), cocoa beans (*Theobroma cacao*), yerba mate (*Ilex paraguariensis*), guarana fruit (*Paullinia cupana*), coffee beans (*Coffea arabica* and *Coffea robusta*), tea leaves (*Camelia siniensis*), etc.

It is usually consumed in beverages, ranging from coffee to energy drinks. It is frequently used by professional drivers, although its effect on the body is relatively short (about 30 min) (Heckman et al. 2010; Sparrow et al. 2019; Owens et al. 2019).

As with other stimulants, addiction can develop with long-term use. This results in a change in blood flow in the brain, leading for example to headaches, drowsiness and reduced alertness (Jones et al. 2000; Juliano et al. 2012).

However, when it comes to its effectiveness for fatigue, it has been shown that successive repeated doses of caffeine (200 mg tested) can radically reduce fatigue behind the wheel and thus eliminate errors arising from drowsy driving (Aidman et al. 2018).

There is always a risk of increased stress from stimulants (especially caffeine-containing substances) based on how the body processes it. In general, it may be advisable to limit the use of stimulants except in acute cases where they are essential for the proper functioning of the body.

CONCLUSION

The article examines the influence of stimulants on the fatigue of young agricultural machinery drivers. Commonly available means for reducing driver fatigue were chosen as stimulants (coffee, tea, maté, guarana, energy drink, lemon extract with sugar). A special test station with automatic reaction time evaluation was developed to test drivers' reaction ability (responsiveness). Furthermore, the effects on the physical condition of the tested persons (systolic blood pressure, diastolic blood pressure, blood pressure amplitude and heart rate) were investigated. The conducted experiments confirmed statistically significant changes in all tested stimulants, except for tea, for which no statistically significant changes in the monitored parameters were observed. Other stimulants had the following effect:

- Lemon extract with sugar impairs responsiveness and decreases blood pressure amplitude
- Guarana decrease in blood pressure (systolic and diastolic)
- Energy drink causes an increase in systolic blood pressure and an increase in blood pressure amplitude
- Coffee decrease in blood pressure amplitude
- Mathé decrease in heart rate.

https://doi.org/10.17221/4/2024-RAE

The results are applicable across various fields. However, the most likely applications are in industry, medicine and especially transport. It benefits primarily drivers of any vehicles and means of transport. The experiment was not based on the state of fatigue and the possibility of reducing it under the influence of support products, as it was not designed as such.

It is recommended to minimise the use of stimulants and limit their use only to cases where fatigue occurs. It is possible to get used to a stimulant by frequent use, and the use of stimulants without fatigue is a burden for the organism, and unpleasant sensations, stress, etc may accompany its application.

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Received: January 17, 2024
Accepted: April 4, 2024
Published online: August 12, 2024