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ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии

საქართველოს სამედიცინო სიახლენი

GEORGIAN MEDICAL NEWS

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GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board since 1994. GMN carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.

GMN is indexed in MEDLINE, SCOPUS, PubMed and VINITI Russian Academy of Sciences. The full text content is available through EBSCO databases.

GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения. Журнал индексируется в MEDLINE, отражён в базе данных SCOPUS, PubMed и ВИНИТИ РАН. Полнотекстовые статьи журнала доступны через БД EBSCO.

GMN: Georgian Medical News – საქართველოს სამედიცინო სიახლენი – არის ყოველთვიური სამეცნიერო სამედიცინო რეცენზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეტყველების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რუსულ და ინგლისურ ენებზე ქვეყნდება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.

ჟურნალი ინდექსირებულია MEDLINE-ის საერთაშორისო სისტემაში, ასახულია SCOPUS-ის, PubMed-ის და ВИНИТИ РАН-ის მონაცემთა ბაზებში. სტატიების სრული ტექსტი ხელმისაწვდომია EBSCO-ს მონაცემთა ბაზებიდან.

WEBSITE

www.geomednews.com

К СВЕДЕНИЮ АВТОРОВ!

При направлении статьи в редакцию необходимо соблюдать следующие правила:

1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman** (**Кириллица**), для текста на грузинском языке следует использовать **AcadNusx.** Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применявшиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи**. Таблицы и графики должны быть озаглавлены.

6. Фотографии должны быть контрастными, фотокопии с рентгенограмм - в позитивном изображении. Рисунки, чертежи и диаграммы следует озаглавить, пронумеровать и вставить в соответствующее место текста **в tiff формате**.

В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

7. Фамилии отечественных авторов приводятся в оригинальной транскрипции.

8. При оформлении и направлении статей в журнал МНГ просим авторов соблюдать правила, изложенные в «Единых требованиях к рукописям, представляемым в биомедицинские журналы», принятых Международным комитетом редакторов медицинских журналов - http://www.spinesurgery.ru/files/publish.pdf и http://www.nlm.nih.gov/bsd/uniform_requirements.html
В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

9. Для получения права на публикацию статья должна иметь от руководителя работы или учреждения визу и сопроводительное отношение, написанные или напечатанные на бланке и заверенные подписью и печатью.

10. В конце статьи должны быть подписи всех авторов, полностью приведены их фамилии, имена и отчества, указаны служебный и домашний номера телефонов и адреса или иные координаты. Количество авторов (соавторов) не должно превышать пяти человек.

11. Редакция оставляет за собой право сокращать и исправлять статьи. Корректура авторам не высылается, вся работа и сверка проводится по авторскому оригиналу.

12. Недопустимо направление в редакцию работ, представленных к печати в иных издательствах или опубликованных в других изданиях.

При нарушении указанных правил статьи не рассматриваются.

REQUIREMENTS

Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or compu-ter-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman** (**Cyrillic**), print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf
In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

11. Editorial Staff reserves the rights to cut down in size and correct the articles. Proof-sheets are not sent out to the authors. The entire editorial and collation work is performed according to the author's original text.

12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned Requirements are not Assigned to be Reviewed.

ავტორთა საყურადღებოდ!

რედაქციაში სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე,დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურენოვან ტექსტებში - **Times New Roman (Кириллица)**, ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx.** შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სიის და რეზიუმეების (ინგლისურ, რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გაშუქდეს: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

4. სტატიას თან უნდა ახლდეს რეზიუმე ინგლისურ, რუსულ და ქართულ ენებზე არანაკლებ ნახევარი გვერდის მოცულობისა (სათაურის, ავტორების, დაწესებულების მითითებით და უნდა შეიცავდეს შემდეგ განყოფილებებს: მიზანი, მასალა და მეთოდები, შედეგები და დასკვნები; ტექსტუალური ნაწილი არ უნდა იყოს 15 სტრიქონზე ნაკლები) და საკვანძო სიტყვების ჩამონათვალი (key words).

5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული, დანომრილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტოსურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი, ანათალების შეღებვის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო, შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ჟურნალის დასახელება, გამოცემის ადგილი, წელი, ჟურნალის №, პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფჩხილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია, რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცენზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა, მეთოდის სანდოობა, შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა, რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქცია იტოვებს უფლებას შეასწოროს სტატია. ტექსტზე მუშაობა და შეჯერება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქციაში ისეთი სტატიის წარდგენა, რომელიც დასაბეჭდად წარდგენილი იყო სხვა რედაქციაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

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PSYCHOPHYSIOLOGICAL RELATIONSHIPS BETWEEN EMOTIONAL STATES AND RESPIRATORY DYNAMICS IN DRIVERS UNDER COGNITIVE LOAD

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Abstract.

This study investigates the relationship between emotional states and respiratory dynamics in drivers operating under varying levels of cognitive load. The research integrates psychophysiological measurements with emotional self-reports to examine how affective processes influence respiratory patterns during driving tasks. A total of 1,000 professional drivers participated in simulated and real-world driving, with 859 valid datasets retained after quality control procedures. Respiratory parameters, including respiratory rate, tidal volume, inspiratory duration, and inspiratory flow, were recorded using wearable sensors. Emotional states were assessed using the Self-Assessment Manikin (SAM) scale and a structured emotional questionnaire measuring stress, negative emotions, fatigue, and related indicators.

The results revealed stable associations between emotional states and respiratory dynamics. Negative emotional states were associated with reduced inspiration time and decreased respiratory variability, indicating more constrained breathing patterns. In contrast, strong emotional activation was associated with increased tidal volume and inspiratory flow, reflecting greater respiratory amplitude. Correlation analysis demonstrated a strong physiological relationship between tidal volume and inspiratory flow ($r \approx 0.90$).

Overall, the findings suggest that respiratory parameters represent sensitive psychophysiological markers of emotional regulation during driving tasks under cognitive load and may contribute to the development of driver monitoring systems aimed at detecting stress and cognitive overload.

Key words. Emotional valence, arousal, cognitive load, respiratory dynamics, psychophysiology, driving.

Introduction.

Emotional and psychophysiological regulation plays a crucial role in an individual's ability to function effectively under conditions of increased cognitive and emotional demands. Contemporary research in psychology and medicine conceptualizes mental well-being as a dynamic psychophysiological system involving the interaction of emotional, cognitive, and physiological processes that enable individuals to adapt to environmental challenges [1,2]. In professional contexts requiring sustained attention and rapid decision-making, the regulation of emotional states and physiological activation becomes a critical factor influencing cognitive functioning and behavioral performance [3,4].

One of the central mechanisms supporting mental health and adaptive functioning is emotional regulation. According to the circumplex model of affect, emotional experiences can be described along two fundamental dimensions: valence, representing the positive or negative quality of an emotion, and arousal, reflecting the level of physiological activation [5,6]. The balance between these dimensions plays a significant role in the regulation of cognitive processes such as attention, working memory, and decision-making [7]. Emotional states characterized by excessive negative valence or extreme arousal may disrupt cognitive functioning, whereas balanced affective states may facilitate optimal information processing [6,8,9].

Psychophysiological studies demonstrate that emotional states are closely linked to autonomic nervous system activity [2,10]. Chronic stress and emotional instability are recognized risk factors for mental health disturbances and can lead to measurable physiological changes, including alterations in cardiovascular, electrodermal, and respiratory activity [2]. These physiological signals provide objective indicators of emotional and cognitive load, making them valuable markers for studying the interaction between mental states and behavioral performance [11,12].

Among these physiological indicators, the respiratory system represents one of the most sensitive and accessible markers of psychophysiological regulation. Variations in breathing rate, respiratory volume, and the temporal structure of breathing cycles reflect the functioning of the autonomic nervous system and are closely associated with emotional tension, stress responses, and cognitive workload [13,14]. In recent years, respiratory parameters have increasingly been considered potential biomarkers of emotional regulation and mental states, as respiration serves as a bridge between voluntary and autonomic control mechanisms.

These psychophysiological processes become particularly relevant in professional activities that require continuous cognitive monitoring and rapid responses to changing environmental conditions. Driving represents a complex cognitive activity involving sustained attention, sensorimotor coordination, working memory, and decision-making under time pressure [3,15,16]. Emotional states experienced during driving, including stress, anxiety, fatigue, or frustration, can significantly influence driver behavior and road safety [17].

Research in transportation psychology indicates that elevated emotional arousal may impair attentional control, increase reaction time, and reduce the ability to make optimal decisions in dynamic traffic environments [7,18]. Negative emotional states may narrow attentional focus and increase susceptibility to errors, while moderate levels of arousal combined with positive emotional valence may support cognitive stability and situational awareness. Understanding the psychophysiological mechanisms underlying these effects is therefore essential for improving both driver safety and mental well-being.

Despite the growing body of research on driver stress and cognitive workload, the relationship between emotional valence, arousal and respiratory dynamics remains insufficiently explored [4,19]. In particular, limited evidence exists regarding how respiratory parameters reflect emotional regulation under cognitive load.

Therefore, the aim of the present study is to examine the relationship between emotional states and respiratory parameters in drivers under varying levels of cognitive load. Special attention is given to respiratory indicators as potential psychophysiological markers of emotional regulation and factors influencing cognitive functioning.

The findings of this study may contribute to a deeper understanding of psychophysiological regulation in complex professional activities and provide a foundation for the development of driver monitoring systems capable of detecting emotional stress and cognitive overload in real time, thereby improving road safety and supporting mental health [19,20].

Materials and Methods.

The relationship between emotional states, and respiratory dynamics in drivers under varying levels of cognitive load was investigated. The research design combined simulated driving tasks, real-world driving experiments, and psychophysiological measurements, with particular attention to respiratory parameters as indicators of emotional regulation under cognitive load [2,13]. A total of 1,000 professional drivers were initially recruited (mean age = 45 years, range = 25–60 years; mean driving experience = 10 years). All participants held valid driver's licenses and reported driving on a daily basis. To comply with ethical standards, drivers signed a document agreeing to participate in the experiment. After data screening, including removal of incomplete sessions, sensor artifacts and physiologically implausible values, 859 valid datasets were retained for final analysis. For paired analyses involving respiratory variables, including inspiratory duration and respiratory rate, all 859 valid observations were used. This procedure ensured a dataset of sufficient quality and size for statistical analysis.

The experimental protocol was designed to induce varying levels of cognitive load in both a controlled driving-simulator environment and real-road driving conditions. The combination of these two modalities increased ecological validity, as previous studies have demonstrated substantial behavioral parallels between simulated and real-world driving under conditions of stress and workload [3,16]. The experimental tasks integrated visual stimuli, auditory instructions, and physiological recordings obtained through wearable sensors, allowing simultaneous characterization of emotional and respiratory responses under cognitive load [19].

Participants and Experimental Setting:

Participants completed the study in a controlled laboratory environment equipped with a full-scale driving simulator featuring a panoramic display and realistic steering and pedal feedback. Driving simulators provide a controlled and safe environment for studying driver behavior and cognitive workload while maintaining ecological validity comparable to real-world driving conditions.

In addition to the simulator sessions, real-road driving assessments were conducted using a vehicle equipped with sensors for physiological and behavioral monitoring. The vehicle allowed continuous recording of respiratory parameters and behavioral responses during natural driving conditions. The two environments were designed to match as closely as possible in terms of task structure, driving scenarios, and cognitive load induction.

Physiological and behavioral signals were recorded using wearable sensor systems integrated with the vehicle and simulator data acquisition platforms, allowing synchronized measurement of driver responses during task performance.

Experimental Procedure:

The experimental protocol consisted of multiple task blocks designed to induce three predefined levels of cognitive load: low, medium, and high. Each block included calibration tasks, cognitive load-inducing tasks, emotional self-report measures, and continuous physiological recordings. At the end of each task block, participants completed a brief questionnaire including both emotional self-report measures and task-related responses corresponding to the immediately preceding time period. The manipulation of task difficulty allowed the assessment of cognitive workload effects on emotional and physiological responses, a methodological approach widely used in mental workload research [4].

Visual stimuli were presented either on the central simulator screen or on a tablet device mounted on the vehicle dashboard. Emotional states were assessed using standardized self-report procedures based on valence and arousal dimensions, commonly applied in experimental emotion research [21,22]. All experimental instructions were delivered verbally via an audio communication system in order to ensure consistent delivery across participants and to minimize additional cognitive demands associated with reading.

Before the experimental trials, participants completed a training and familiarization stage. During this phase, each task type was demonstrated, and participants were given the opportunity to practice the procedures. When necessary, the experimenter provided additional guidance or repeated the practice block to ensure that all participants fully understood the task requirements prior to entering the experimental phase.

Cognitive Load:

The task set was designed to induce varying levels of cognitive load through memory, attention, and information-processing demands. Psychophysiological responses, particularly respiratory dynamics, were continuously recorded during task execution in order to examine the relationship between cognitive load, emotional activation, and physiological regulation. The task sequence consisted of three primary components. These tasks were used to manipulate cognitive load rather than to provide direct cognitive performance outcomes in the present analysis.

1. Detail Memory Task:

Participants viewed either a static image or a 30-second video depicting a traffic-related scenario. After viewing, they answered a set of five multiple-choice or short-answer questions related to scene details (e.g., "What color was the car on the left side?", "How many pedestrians were visible?", "Which road sign appeared near the intersection?"). The scenarios varied in environmental complexity to modulate cognitive load and emotional engagement. Respiratory activity was monitored throughout the viewing and response phases to examine

physiological responses associated with attentional engagement and memory-related processing.

2. Target Detection Task:

Participants were instructed to locate a specified object, such as a number, sign, or symbol, embedded among 10–15 distractor stimuli presented on the screen for 10 seconds. This task required rapid visual search under time constraints and engaged selective attention and perceptual discrimination. Some studies have shown that emotional stimuli may interfere with attentional control and information processing [7,18]. During the task, respiratory parameters were recorded to examine changes in physiological activation associated with attentional effort and time pressure.

3. Question Formulation Task:

Participants were presented with a stimulus and instructed to formulate two meaningful questions about a target object (e.g., "Why is the vehicle positioned this way?"). This task was designed to assess deeper cognitive processing, semantic integration, and conceptual reasoning. Because this task required higher-order cognitive processing, it was expected to produce increased cognitive load and corresponding psychophysiological responses. Respiratory measurements collected during this task were used to examine changes in breathing patterns associated with cognitive effort and emotional regulation.

Auditory Attention Task:

To impose an additional layer of cognitive load, participants completed an auditory working memory task embedded within driving conditions. During this task, participants listened to sequences of numbers or words and were asked to repeat them in forward or reverse order. This dual-task paradigm simulated real-world driving situations in which drivers must simultaneously respond to external auditory cues such as navigation instructions or in-vehicle alerts, while maintaining continuous control of the vehicle. Dual-task paradigms are commonly used in driving research to investigate cognitive workload and attentional resource allocation [3,4,23].

Throughout the auditory attention task, respiratory activity was continuously recorded in order to examine psychophysiological responses to increased cognitive demands. Variations in respiratory rate and breathing cycle structure were considered as indicators of physiological activation associated with working memory load and attentional effort.

Driving Load Levels:

Three levels of cognitive load were implemented in the driving simulator to systematically manipulate task difficulty and emotional activation during driving.

Low Load: Driving on a straight, low-density highway with no pedestrians, no vehicles, and minimal visual complexity. Speed limits were enforced, but no unexpected events occurred. This condition represented baseline driving with minimal cognitive demand.

Medium Load: Driving in moderate traffic conditions requiring monitoring of road signs, traffic lights, lane positions, and the behavior of surrounding vehicles. Moderate levels of unpredictability were introduced, increasing attentional demand and decision-making requirements.

High Load: Driving conditions involving sudden obstacles and events, such as unpredictable pedestrian crossings, abrupt braking by the preceding vehicle, erratic lane changes by other cars, or sudden auditory alerts. These situations correspond to established experimental paradigms used to induce high cognitive workload and emotional stress in driving research [3,4].

During all driving conditions, respiratory parameters were continuously monitored to examine psychophysiological responses to varying levels of cognitive load and emotional stress.

In addition to the controlled simulator conditions, real-world "City driving" sessions were conducted in urban environments across different time periods (e.g., daytime, rush hours, and nighttime). This condition represents naturalistic driving with varying traffic density and environmental complexity and therefore encompasses a range of cognitive load levels rather than a single predefined category.

Physiological Measurements:

Physiological indices were recorded continuously using clinically validated wearable sensors attached to the torso and abdomen. Key respiratory parameters included: Respiratory Rate (breaths per minute); Tidal Volume (volume of air per breath); Inspiratory Duration (length of the inhalation phase); Inspiratory Speed (rate of air intake).

These parameters were selected due to their sensitivity to changes in both emotional valence and arousal, making them suitable markers for the integration of cognitive and emotional dynamics in driving.

Respiratory signals were recorded continuously throughout the experimental tasks and subsequently segmented into predefined time interval (30, 60, and 120 seconds) for analysis of temporal variations in respiratory dynamics across different levels of cognitive load.

Emotional Assessment:

Emotional state was assessed using two complementary methods: the Self-Assessment Manikin (SAM) scale [21] and a structured self-report questionnaire developed for the study.

SAM Scale Dimensions:

- **Valence:** from very unpleasant (1) to very pleasant (8)
- **Arousal:** from calm (1) to highly aroused (8)
- **Dominance:** from controlled (1) to submissive (8)

SAM ratings were collected during the experimental tasks and immediately after each task block.

Structured Emotional Questionnaire:

To obtain more context-specific emotional data, participants completed a questionnaire consisting of the following items, each rated on an eight-point Likert scale [21]:

1. **Stress Level:** perceived intensity of stress during each task block.
2. **Dry Mouth Sensation:** a physiological correlate of stress and anxiety during driving.
3. **Calmness:** assessment of emotional stability and relaxation.
4. **Negative Emotional Intrusion:** likelihood of experiencing distracting negative thoughts.
5. **Fatigue:** subjective experience of physical and mental exhaustion.

This multidimensional assessment approach aligns with psychophysiological methodologies commonly employed in driving research and allows for the integration of emotional reports with physiological data under varying levels of cognitive load. Emotional self-report measures were collected following each cognitive load condition. While respiratory signals were analyzed using predefined time windows (30, 60, and 120 seconds), these windows represent analytical segments rather than discrete questionnaire time points. For correlation analysis, emotional ratings were aligned with the corresponding experimental condition from which the respiratory data were derived.

Calibration Tasks:

Each load block began with calibration procedures designed to standardize baseline conditions:

1. **Dot Tracking Task:** Participants followed a moving dot (2 cm diameter, speed 5–10 cm/s) on the screen using either head movements or eye movements. This assessed visuomotor coordination and attentional consistency.
2. **Breathing Calibration:** Participants performed synchronized deep inhalations with specific steering wheel turns. This task established baseline respiratory–motor interaction patterns for later comparison under cognitive load.

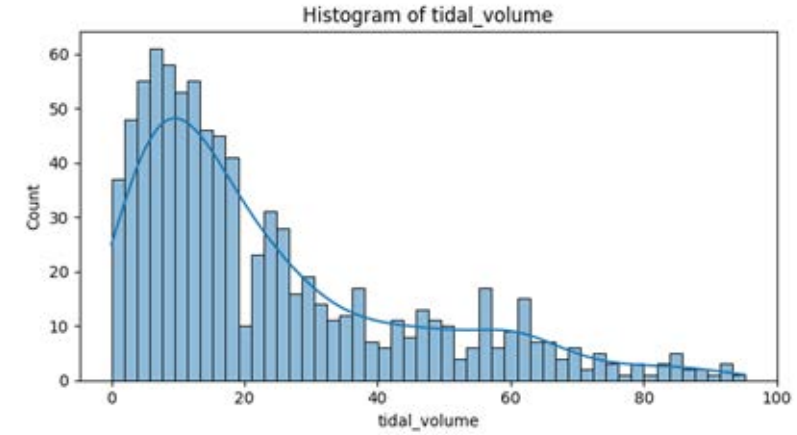

Figure 1. *Tidal volume indicators.*

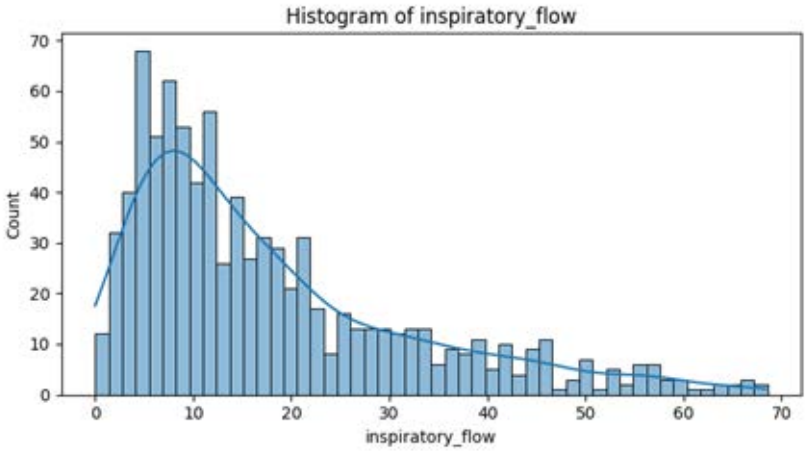

Figure 2. *Inspiratory flow indicators.*

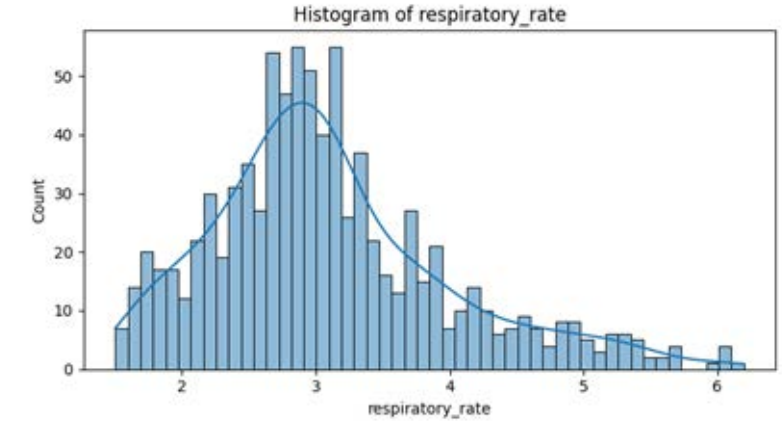

Figure 3. *Respiratory rate indicators.*

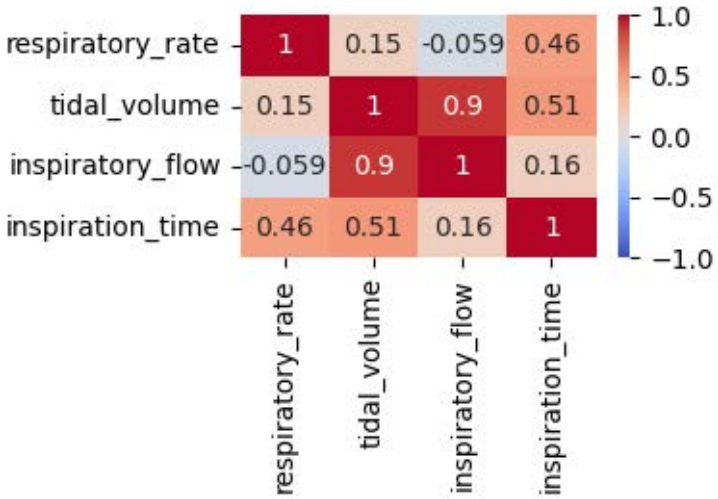

Figure 4. *Heatmap of correlations between respiratory variables.*

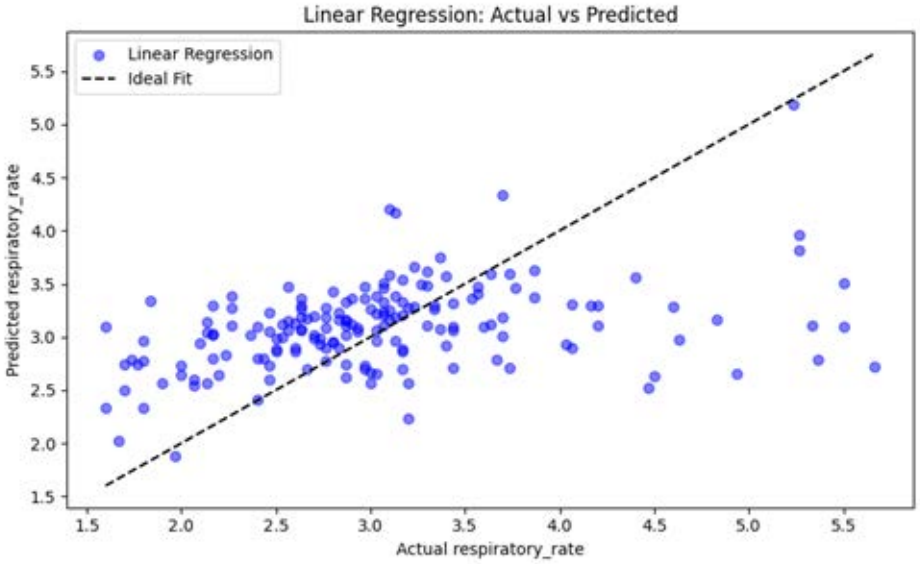

Figure 5. *Linear regression: actual and predicted respiratory rate values.*

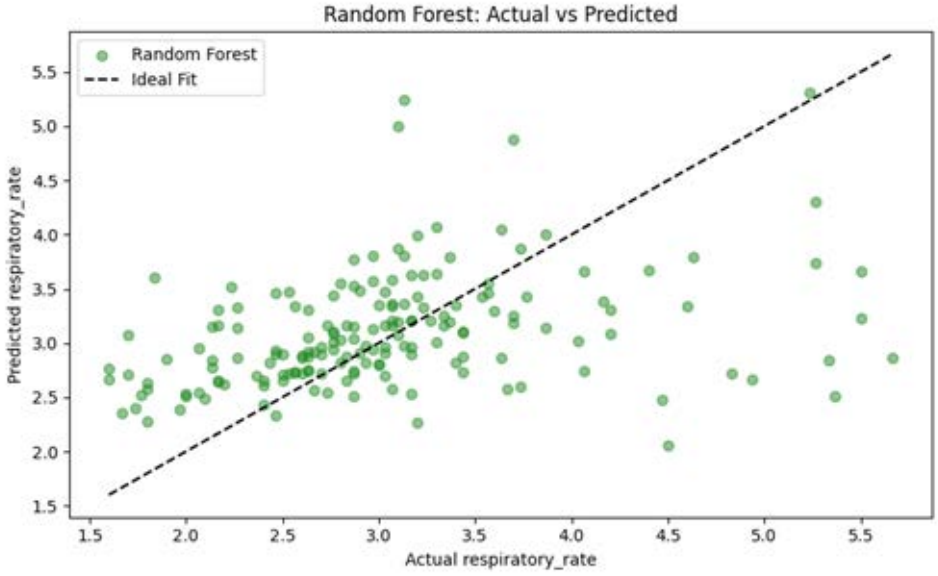

Figure 6. *Random forest: actual and predicted respiratory rates.*

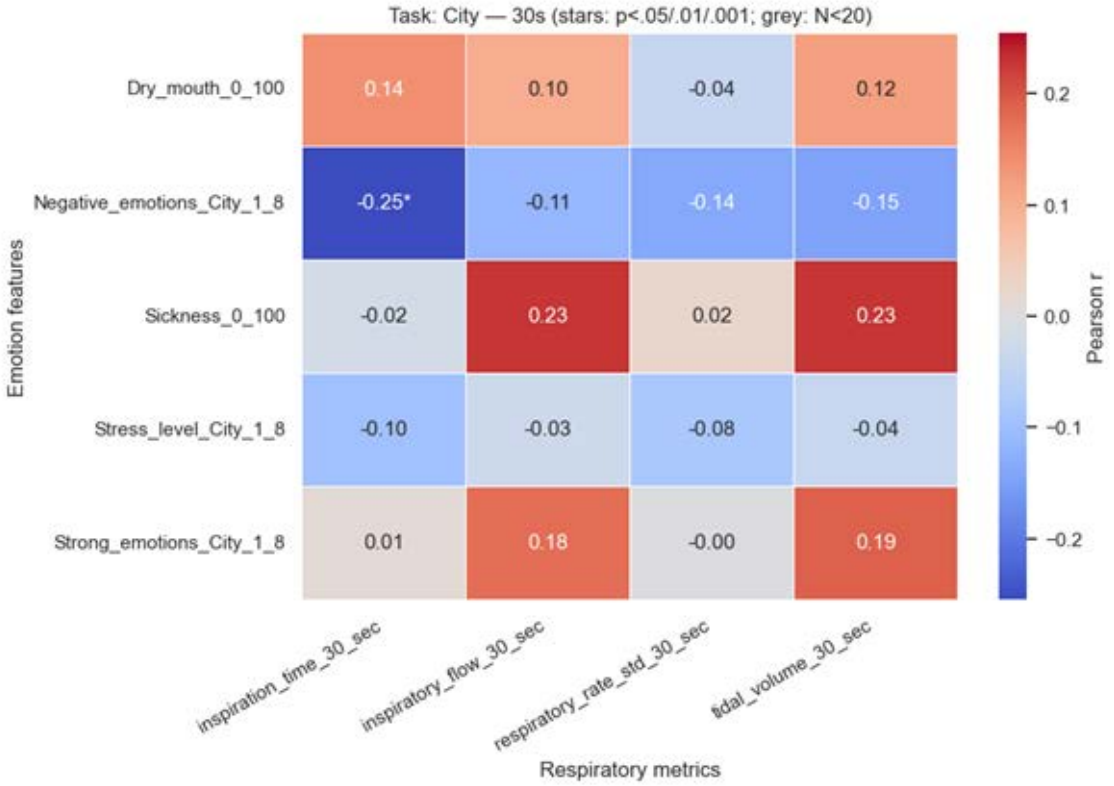

Figure 7. *Correlations between emotions and breathing - City task (30 seconds).*

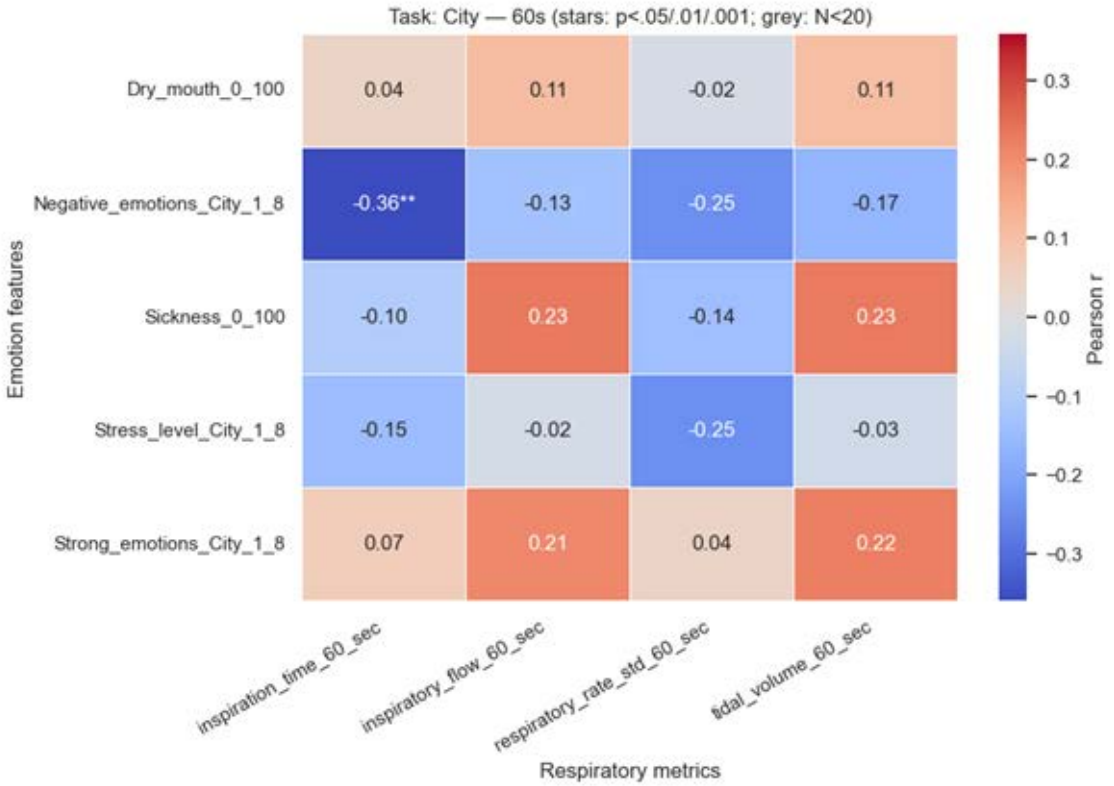

Figure 8. *Correlations between emotions and breathing – City task (60 seconds).*

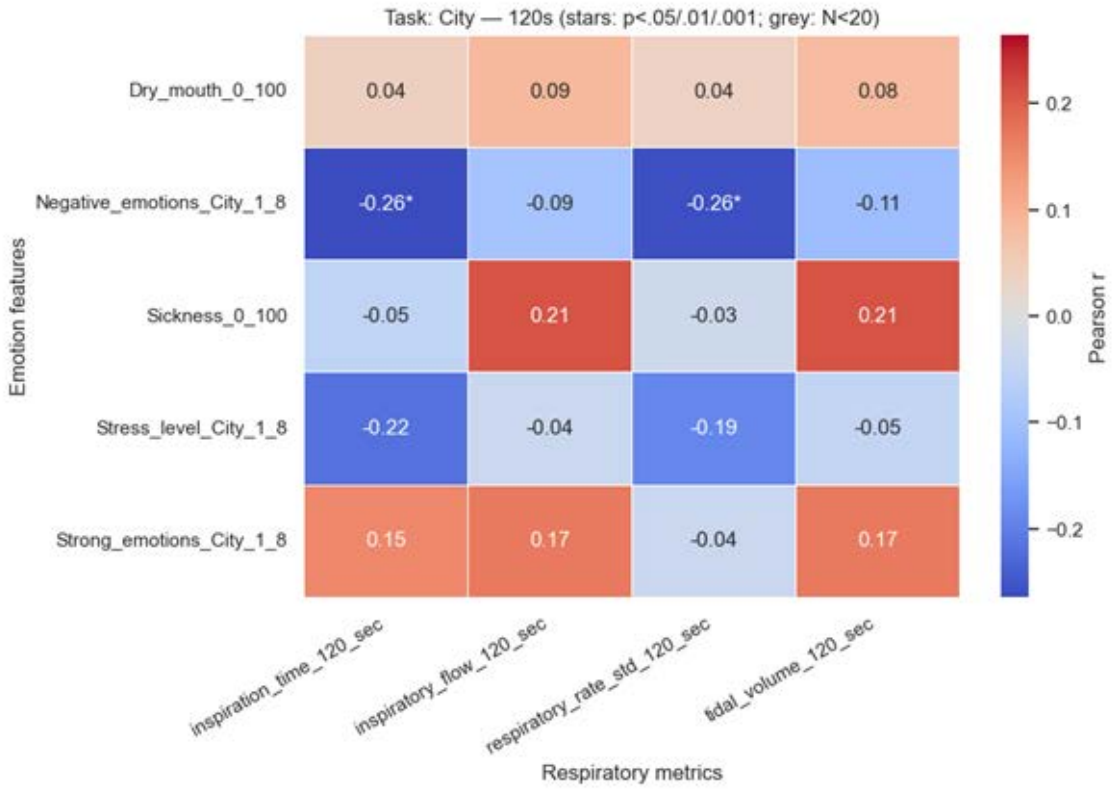

Figure 9. *Correlations between emotions and breathing – City task (120 seconds).*

Table 1. *Predictive performance of respiratory rate models (MSE, MAE, R²).*

Model	**MSE**	**MAE**	**R²**
Linear Regression	0.610	0.580	0.134
Random Forest	0.673	0.587	0.046

Data Processing and Quality Control:

All physiological and behavioral data underwent preprocessing, including filtering to remove artifacts due to movement, signal loss, or incorrect sensor placement. Unrealistic respiratory values (e.g., respiratory rate below 5 or above 45 breaths per minute) were excluded. Only trials with fully completed task procedures were retained for analysis.

Ethical Considerations:

The study was approved by the Ethics Committee of Yerevan State University and was conducted in accordance with recognized ethical guidelines. Written informed consent was obtained from all participants prior to data collection (protocol code: N6, 25.03.26).

Results.

Analysis of distributions of respiratory parameters:

The histogram of tidal volume shows pronounced asymmetry, with most values up to 30 ml, indicating a predominance of relatively small breaths. Rare deep breaths of up to 90 ml form a long right-hand tail, reflecting high variability in respiratory amplitude (Figure 1).

This pattern highlights the adaptive nature of respiration: typical breaths are small and regular, while occasional deep inhalations demonstrate flexibility in response to physiological or emotional demands. Both average values and distributional characteristics are important for understanding respiratory behaviour.

The distribution of inspiratory flow has a similar pattern: the modal values are within 5–15 conventional units, while values above 50 are rare. At the same time, a long right tail extends up to 70 conventional units (Figure 2). This indicates the predominance of moderate inhalation rates with occasional high-intensity peaks. The similarity in distribution shape with tidal volume reflects their physiological relationship.

The respiratory rate is presented by a more compact and closer to a normal distribution with minor asymmetry. Most indicators are concentrated in the range of 2.5–3.5 conventional units, and values above 5 are observed only occasionally (Figure 3). This suggests the relative stability of the respiratory cycle rate compared to the indicators of the depth and strength of inspiration.

Thus, the obtained inspiratory distributions show that the variability of the respiratory process is largely determined by the parameters of the depth and intensity of inhalation (tidal volume and inspiratory flow), whereas the respiratory rate is a more stable physiological indicator. This characteristic is consistent with established physiological understanding that the respiratory rate is maintained within a narrow range due to regulatory mechanisms, while the volume and flow of

inspiration are adapted to the current functional requirements of the organism, in particular the presence of stress.

To assess the relationships between key respiratory parameters, a correlation analysis was performed (Figure 4). The strongest correlation was found between tidal volume and inspiratory flow ($r \approx 0.90$, $p < 0.001$), indicating a close physiological relationship: an increase in inspiratory volume is typically accompanied by an increase in inspiratory flow. In addition, a moderate positive correlation was found between tidal volume and inspiration time ($r \approx 0.51$, $p < 0.001$), indicating an extension of inhalation at higher respiratory volumes. Interesting results were obtained for the inspiration time – respiratory rate pair. For respondents (N = 859), significant Pearson ($r = 0.462$, $p = 9.6 \times 10^{-47}$) and Spearman ($\rho = 0.438$, $p = 1.4 \times 10^{-41}$) coefficients were found, which indicate a stable positive relationship of medium strength. This means that the prolongation of inhalation time in the studied sample is associated with an increase in the respiratory rate. However, the magnitude of these coefficients ($r < 0.5$) suggests that the respiratory rate remains a relatively autonomous parameter, which is also influenced by other regulatory factors.

At the same time, the relationships between respiratory rate and the parameters of inhalation depth and force (tidal volume and inspiratory flow) were weak ($r \approx 0.15$ and –0.06, respectively). This emphasizes the relative independence of the respiratory cycle frequency from the amplitude characteristics of breathing.

Thus, the results of the analysis show that the variability of the respiratory process is largely determined by amplitude-related characteristics (tidal volume and inspiratory flow), while the respiratory rate and inhalation duration form a partially distinct but statistically significant pattern of association reflecting the adaptive mechanisms of respiratory regulation.

To further explore the relationships between respiratory parameters, an additional modeling analysis was conducted to examine whether respiratory rate could be inferred from other components of the respiratory cycle. Two machine learning models were built: linear regression and random forest. The predictors included tidal volume, inspiratory flow, as well as derived variables.

The results of the quality assessment of the models using standard metrics, mean squared error (MSE), mean absolute error (MAE), and coefficient of determination (R^2), are presented in the table below (Table 1).

Graphical analysis (Figure 5, 6).

Comparison of actual and predicted values showed:

- In the case of linear regression, the predictions are slightly more concentrated around the ideal fit line, indicating marginally better agreement with observed values compared to the random forest model.
- For the random forest model, the spread of predictions is wider, with greater variability particularly at higher values, indicating reduced predictive stability.

Interpretation of results:

- Linear regression showed slightly better results: $R^2 \approx 0.13$, indicating weak but still statistically significant explanatory power.
- Random forest, despite its ability to model nonlinear relationships, demonstrated low quality in this task ($R^2 \approx 0.05$), only slightly improving the MAE compared to the linear model.
- Both algorithms predict respiratory rate with a mean absolute error of ~0.58, which is comparable with the variance of the original data.

Respiratory rate remains a difficult parameter to predict based on the volume-time characteristics of the respiratory cycle. From a physiological perspective, this result supports the relative independence of respiratory rate from amplitude-related parameters such as tidal volume and inspiratory flow. In the context of the present study, this finding indicates that respiratory rate may reflect partially distinct regulatory mechanisms and should be considered separately when examining emotion-related changes in respiratory dynamics. Despite statistically significant correlations with individual features (e.g. inspiration time), their combined influence explains only a small proportion of the variability in the indicator. This supports the autonomy of respiratory rate regulation and the need to involve additional physiological variables to build more reliable predictive models.

In the experiment, along with physiological parameters of breathing, emotional indicators (Negative emotions, Strong emotions, Stress, Sickness, Dry mouth) were considered. This allowed us to study the relationship between the affective state of the participants and the characteristics of the breathing cycle.

Correlation analysis (City driving):

The heatmaps presented in Figures 7–9 illustrate the strength and direction of associations between emotional indicators and respiratory parameters across different analytical time windows (30, 60, and 120 seconds). Consistent patterns are observed across all intervals, indicating stable psychophysiological relationships.

Analysis of correlations in the “City driving” condition, representing naturalistic driving with variable cognitive load, showed consistent patterns:

- Negative emotions showed significant negative correlations with inspiration time (–0.25 at 30s, –0.36 at 60s, –0.26 at 120s; $p < 0.05/0.01$). This indicates that an increase in negative affect is accompanied by a shortening of inhalation, meaning that breathing becomes shorter in duration.
- 120 s condition also showed a negative correlation between Negative emotions and respiratory rate variability ($r = –0.26$, $p < 0.05$), which indicates a decrease in respiratory variability with a stable negative emotional background (Figure 9).
- Strong emotions had positive, albeit moderate, associations with tidal volume and inspiratory flow ($r \approx 0.17–0.22$), reflecting a tendency toward deeper and more intense inhalations
- Additional somatic indicators (Sickness, Dry mouth) showed weak positive associations with respiratory volume parameters, which can be considered as secondary manifestations of physiological discomfort.

These patterns were visually consistent across all heatmaps, confirming the robustness of the observed relationships.

Comparative analysis:

Dividing participants into groups with low (≤3) and high (≥6)

levels of emotional scales (rated on an 8-point scale) confirmed these effects:

- At high levels of negative emotions, breathing became irregular, with a shortening of inspiration time and decreased respiratory rate variability ($p < 0.05$ after FDR (False Discovery Rate) correction).
- During strong emotional activation, a tendency toward increased respiratory amplitude (tidal volume, inspiratory flow) was observed, corresponding to the activation component of the emotional response.
- The effects were of moderate size (Cohen's $d \approx 0.5–0.6$), suggesting that they are psychologically meaningful and potentially relevant in applied contexts.

Discussion.

Overall, the findings indicate that respiratory parameters are sensitive psychophysiological markers of emotional activation during driving tasks. The results support the view that emotional valence and arousal influence the temporal and amplitude characteristics of breathing, which are relevant for understanding psychophysiological regulation under cognitive load.

Negative emotional states were consistently associated with shorter inspiration time and lower respiratory variability. This pattern suggests that negative affect is accompanied by more constrained and less flexible breathing, which may reflect increased physiological tension and reduced regulatory adaptability. The stability of these associations across different time windows indicates that such respiratory changes may serve as reliable markers of negative emotional load in driving contexts.

In contrast, strong emotional activation was associated with increased tidal volume and inspiratory flow. This finding suggests that heightened arousal is reflected primarily in the amplitude of breathing rather than only in respiratory timing. Together, these results indicate that different emotional dimensions may influence different components of the respiratory cycle: negative emotional states appear to compress the temporal structure of breathing, whereas strong arousal increases respiratory intensity.

The strong association between tidal volume and inspiratory flow supports their close physiological relationship, while the weaker associations involving respiratory rate suggest that this parameter remains relatively autonomous. The limited predictive performance of the regression and random-forest models is consistent with this interpretation, indicating that respiratory rate cannot be reliably inferred from volume-time characteristics alone. This result further suggests that respiratory rate may reflect a partially independent component of respiratory regulation and therefore should be interpreted in future separately from volume-based measures in emotion-related analyses. From an applied perspective, the results suggest that respiratory indicators may be useful components of driver monitoring systems, especially for early detection of emotional stress and increased cognitive load. At the same time, respiration alone is unlikely to be sufficient for comprehensive classification, and future work should combine respiratory measures with additional physiological signals.

The findings support psychophysiological models suggesting that respiration is a multidimensional marker of emotional regulation. Temporal parameters of breathing appear to be more sensitive to negative affect, whereas amplitude-related parameters are more strongly associated with heightened arousal. Practically, these results may inform the development of driver-state monitoring systems that use respiration-based indicators to detect emerging stress and maladaptive emotional activation during driving.

Limitations.

This study has several limitations that should be considered when interpreting the findings. First, although the study combined simulated and real-world driving conditions, physiological recordings in dynamic environments are susceptible to motion artifacts and environmental noise, which may affect signal precision.

Second, emotional states were assessed using self-report measures, including the Self-Assessment Manikin (SAM) scale and structured questionnaires, which may be influenced by subjective bias and individual differences in emotional awareness. In addition, although emotional ratings were collected in relation to experimental conditions, some degree of recall bias may still be present, as self-reported measures reflect subjective evaluation rather than continuous real-time emotional tracking.

Third, the cross-sectional design of the study does not allow for causal inference, and the observed relationships between emotional states, respiratory dynamics, and cognitive load should be interpreted as correlational.

Fourth, although significant associations between emotional indicators and respiratory parameters were identified, the predictive models demonstrated limited explanatory power, indicating that additional physiological variables (e.g., heart rate variability, electrodermal activity) may be necessary to fully capture psychophysiological regulation.

Conclusion.

Emotional states are systematically associated with respiratory dynamics in drivers under cognitive load. Negative emotions were linked to shorter and less variable breathing, whereas strong emotional activation was associated with greater respiratory amplitude. These findings indicate that respiratory parameters can serve as useful psychophysiological markers of emotional regulation in driving conditions. Although respiration alone does not fully characterize driver psychophysiological state or predict respiratory rate with high accuracy, but it also provides valuable information for understanding psychophysiological regulation and may contribute to future multimodal monitoring systems.

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